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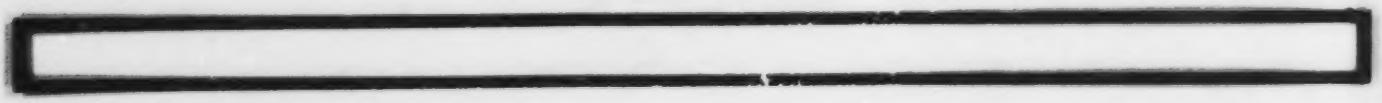
Reevaluation of NMHC Emission Reduction Requirements in Northeastern Illinois and Southeastern Wisconsin Using the Empirical Kinetic Modeling Approach (EKMA)

Illinois State Environmental Protection Agency
Springfield

May 83



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Illinois Environmental Protection Agency
Division of Air Pollution Control
2200 Churchill Road
Springfield, Illinois 62706

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16. Abstract (Limit: 200 words)

This report refines in modeling that was first done for the 1982 Ozone State Implementation Plan and submitted to the USEPA in April 1982 to fulfill Clean Air Act requirements. Three key input variables were reevaluated in this report: Ozone aloft, NMHC/NO_x ratio, and initial NMHC and NO_x concentrations. The report contains revised emission reduction estimates for both northeast Illinois and southwest Wisconsin.

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I. Summary

This document presents the results of further analyses conducted by IEPA in the use of EKMA to estimate emission control requirements in the Chicago and southeastern Wisconsin areas. This work is supplemental to work that was done for the April 1982 Ozone State Implementation Plan (SIP) submittal and the IEPA's response to comments on that SIP, submitted to USEPA Region V on December 3, 1983. Except where explicitly revised herein, statements and analyses in the 1982 SIP and response to comments referred to above continue to represent IEPA's position concerning modeling issues and procedures.

Although IEPA has not had the opportunity to address all of the uncertainties encountered in the EKMA procedure, several key inputs have been reevaluated, and when taken together, they produce reasonable estimates of emission reduction requirements. These key inputs are:

(1) ozone (O_3) aloft
(2) NMHC/NO_x ratio
(3) initial NMHC and NO_x concentrations

Based upon its reevaluation of these input variables, IEPA has determined that the best estimates of emission reduction requirements for Chicago and southeastern Wisconsin are as follows:

Monitor Site	Emissions Reduction Required to Achieve the Ozone National Ambient Air Quality Standard (from 1980 Base)
Waukegan, Illinois	17%
Kenosha, Wisconsin	22%

These estimates, although satisfactory for use as estimates of control, are variable by an unquantifiable amount due to unresolved questions concerning assumptions that are internal to the EKMA model. However, these results are supported by statistical model results which indicate that 16 percent and 26 percent emission control are required in Illinois (Waukegan) and Wisconsin (Kenosha), respectively.

II. Review of Previous Studies

A. The July 1982 IEPA SIP Submittal

When preparing the 1982 State Implementation Plan (SIP) it was found that ambient air quality in the Chicago and East St. Louis areas had improved at a much faster rate than predicted in the 1979 Ozone SIP. The results of IEPA analyses indicated that EKMA appeared to significantly overpredict the amount of emission control necessary to attain the air quality standard in Illinois when compared to historical air quality improvement and other modeling techniques. As a result, the IEPA recommended that the results of the EKMA analysis be viewed in the context of these uncertainties.

Strict application of the EKMA model provides a single emission control estimate. For the 1982 ozone SIP, the IEPA identified a range of emission control requirements based on the quality of the input data and potential bias of the model itself. The range concept accommodates the uncertainty and potential over- or underprediction of emission reduction requirements.

B. The USEPA's Response to the IEPA's Initial SIP Submittal

The USEPA responded to the Illinois SIP in a comment letter on August 23, 1982. The basic USEPA position was that IEPA should provide a single best estimate of NMHC emission control. In order to achieve this, the USEPA requested that IEPA use a typical NMHC/NO_x ratio and not make further adjustments to model results.

C. IEPA Response to the USEPA; August 23, 1982 Comments

The IEPA responded to USEPA's August 23, 1982 comments with a letter/submittal on December 3, 1982. The IEPA questioned whether a "single best control estimate" could be determined with sufficient certainty to provide meaningful results. The NMHC/NO_x ratio is crucial to the EKMA procedure and is key to the calculation of a single control requirement value. The USEPA guidance states, "In the event the quality-assured NMHC and NO_x data cannot be obtained for a sufficient number of (high ozone) days to provide a reliable estimate of the prevailing NMHC/NO_x ratio, city-specific EKMA cannot be used" (Ref. 1). The thrust of the reanalysis effort described in the following sections of this report, therefore, is to reevaluate EKMA inputs to determine if the EKMA model can be used to establish a single best estimate of emission control requirements.

III. Limitations of the EKMA Procedure as Applied in Illinois

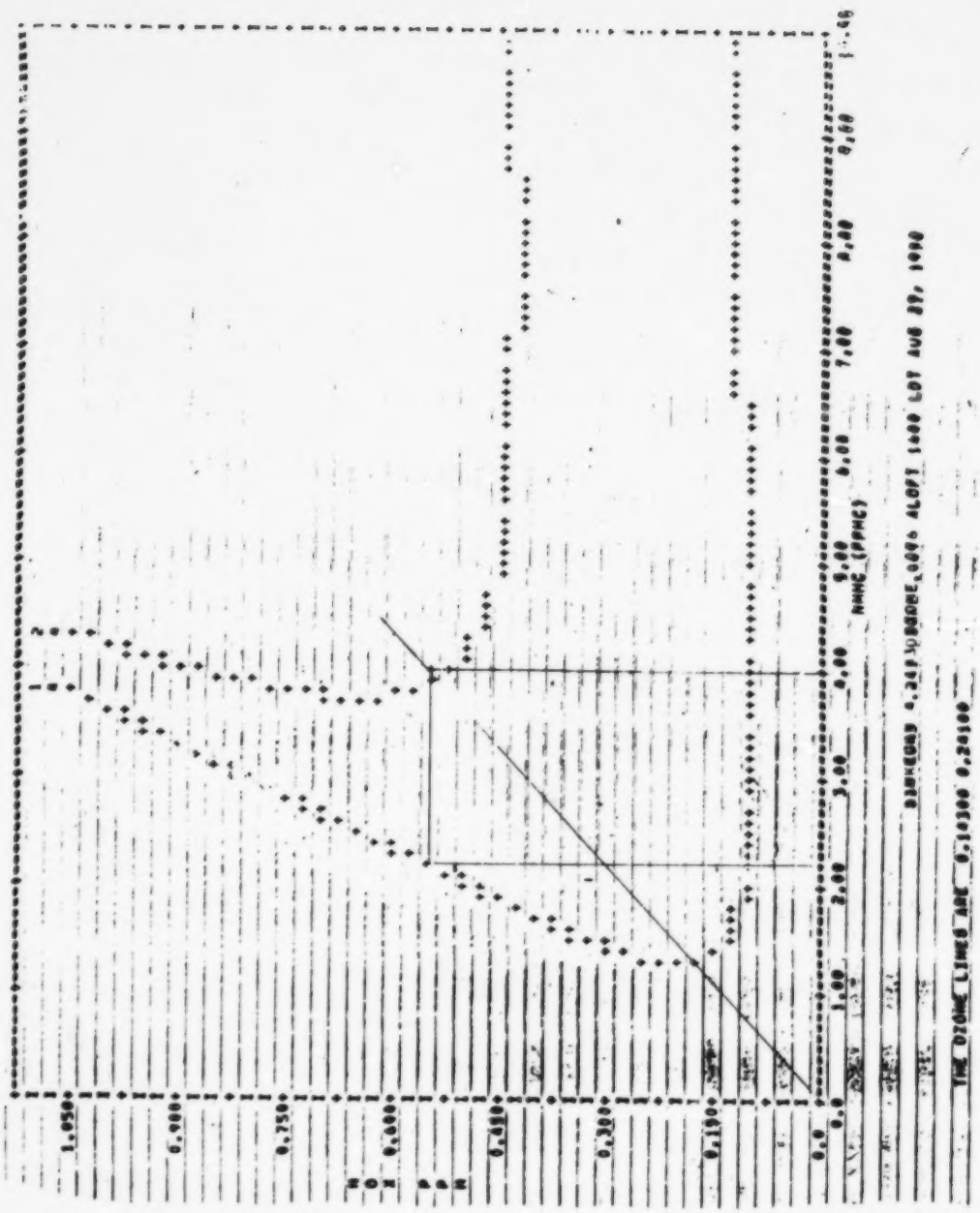
During preparation of the 1982 Ozone SIP and in the months that followed its submittal to USEPA, IEPA has been concerned with the precision and potential bias of the EKMA model results and with the impact that such inaccuracies may have on the ability to prepare an adequate plan. This section describes in some detail what these perceived shortcomings are and their effect on plan results. The areas of most concern are related to a) the model's ability to give consistent results from one year to the next during known decreases in emissions and improved air quality, b) the uncertainty associated with establishing a proper NMHC/NO_x ratio, c) the inability to verify assumed ozone aloft data, d) questions concerning the reactivity assumed by the model and its applicability in the Chicago area, and e) the inability of the model to predict peak regional ozone levels either in a relative or absolute sense.

Not all of these deficiencies were identified or understood to be a potential problem prior to the July SIP submittal. Specifically, items "c" and "e" were found to be potential problems well after the July submittal and only after IEPA had an opportunity to further review the EKMA modeling procedure. This section describes more fully these deficiencies and their impact upon selection of an appropriate emission reduction target. Section IV describes how IEPA has resolved these problems to the extent that the model can produce reliable emission reduction results.

A. Discrepencies in Application of the EKMA Procedure as Applied in Illinois

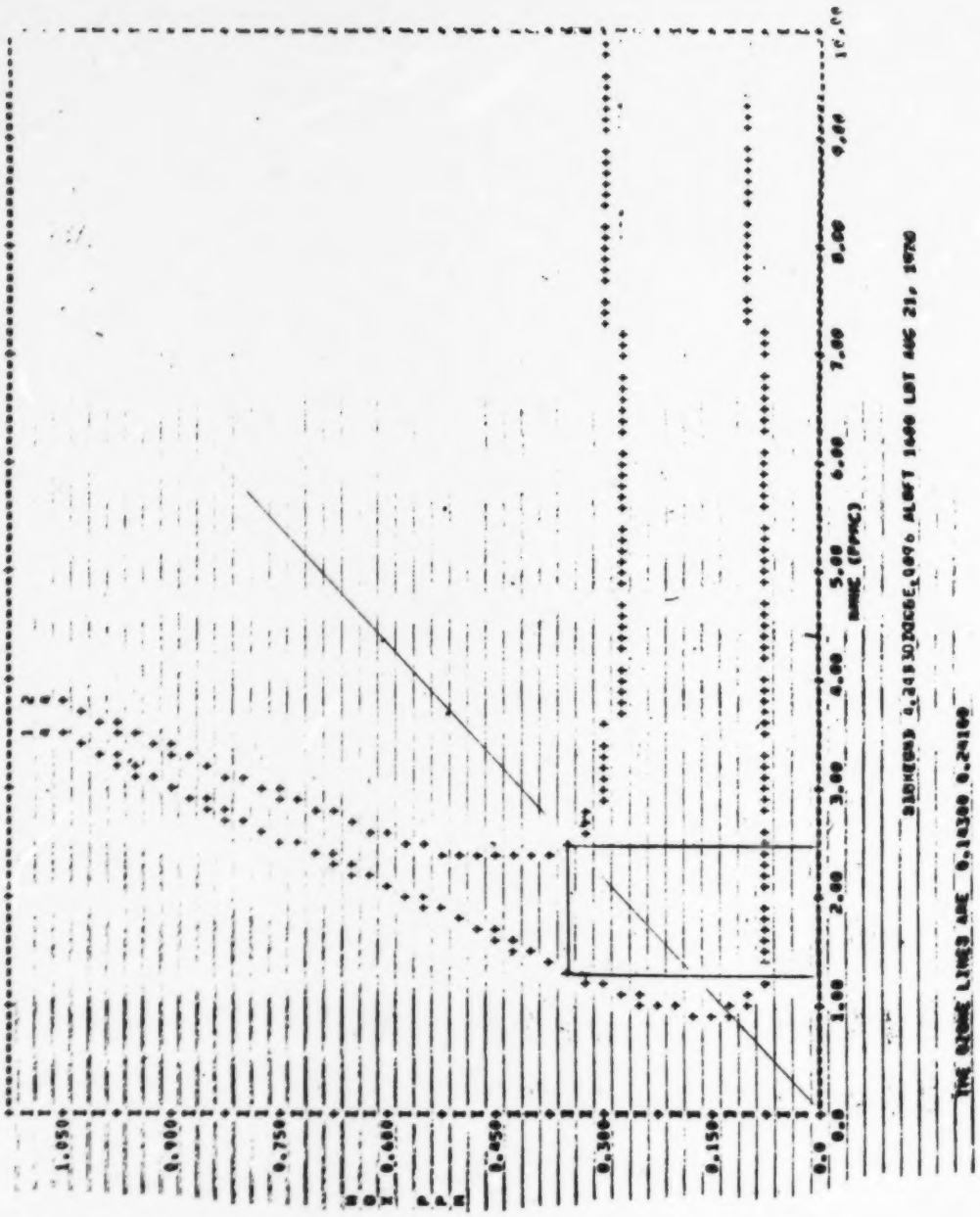
In prepartion of the 1982 SIP submittal, it was found that the design value for Illinois was 0.143 ppm, observed at Waukegan on August 29, 1980. Since Waukegan was also the design site for the 1979 SIP (Waukegan, August 21, 1976; 0.241 ppm) a check was made to determine the amount of emission reduction that would be necessary to bring the ozone design value determined in 1976 down to the current design value. Figure 1 is a composite EKMA isopleth which plots the 0.241 ppm and 0.143 ppm isopleths. The comparison is facilitated by the fact that the time of year is reasonably close for each day (August 21 vs. August 29) and that the NMHC/NO_x ratio for both analyses was assumed to be 7.2:1. As indicated in Figure 1, the resultant control requirment is 45%. During the same time period, only a 17% reduction in NMHC had occurred.

Figure 1



Further comparisons were made to determine if using similar inputs for other variables could explain this discrepancy. Inputs that were changed for different runs were: Date of violation (8/21 on both runs), use of 250 meter morning mixing height in both runs, using 1980 emission fractions on both runs, and using the 1976 afternoon mixing height on both runs. These analyses showed that the discrepancy widened, resulting in a 48% emission reduction or a 31% discrepancy (see Figure 2). As indicated in IEPA's December 3, 1982, response to comments, there are several possible reasons for discrepancy between runs; however, as delineated in the IEPA response, not all of the discrepancy can be related to factors which are not EKMA procedure-related. As indicated in Section IV, IEPA has, through reevaluation of model inputs, determined that judicious selection of model inputs can eliminate this discrepancy.

Figure 2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B. Uncertainty of the NMHC/NO_X Ratio Data

One of the primary reasons Illinois selected the range concept was due to lack of confidence in the ambient NMHC and NO_X data, and the critical nature of this model input. Contacts IEPA has made with other states that prepared 1982 ozone SIP's indicate that the problem of poor correlation of the NMHC and NO_X monitoring data with inventory data is not unique to Illinois. Like Illinois, most other states either did not collect NMHC data in 1979 and 1980, or the available data was invalidated by monitoring specialists. Most other states determined their NMHC/NO_X ratios by using a median of just a few days of high ozone data, or took a median of a few 1981 days having meterological conditions similar to high ozone days. In addition to potential inaccuracy, NMHC and NO_X monitors are at best only representative of very localized conditions. IEPA has evaluated the accuracy of the 1981 NMHC and NO_X data and, through the results of federal audits, has determined that the NMHC and NO_X data collected at the 160 North LaSalle monitoring site is expected to be highly accurate. Comparisons of monitored and emission inventory-determined NMHC/NO_X ratios, as determined from the mobile source inventory, correlate very well. However, that analysis also shows that the monitors at 160 North LaSalle are placed in an area that is atypical in terms of mobile source emissions. In Section IV.A., procedures are described which reconcile the monitored NMHC/NO_X ratio with inventory generated ratios which result in a more accurate estimate of NMHC/NO_X for use in EKMA. Using that ratio produces results that mitigate much of the discrepancy in model results that are described in Section III. A. above.

C. The Effect of Ozone Aloft

Another key input to the EKMA procedure, in terms of its effects on estimated NMHC emission reduction, is ozone aloft. This is the level of ozone concentration above the morning mixing layer, and is assumed by the model to be constant over the period of the day that the mixing height is increasing. USEPA guidelines recommend using the average of 10:00 a.m. and 11:00 a.m. ozone concentrations at upwind monitoring sites in areas that are generally removed from urban scavaging effects. IEPA used the USEPA recommended procedure in estimating ozone aloft in it original SIP submittal.

Since responding to USEPA comments on the SIP in December, IEPA has had an opportunity to reevaluate the procedure used in estimating ozone aloft. This reevaluation consists of examining ozone aloft data which the Agency has collected at the Sears Tower monitor in downtown Chicago during the summer

months of 1978 and 1979. The procedure utilized by IEPA to reevaluate ozone aloft measurements in light of this data is described in Section IV.B. By making corrections to estimated ozone aloft data based upon actual ozone aloft, the EKMA procedure produces results that are more in line with the statistical analysis results, and tend to minimize the observed overprediction of EKMA when run in the calculate mode. The procedure IEPA used to make adjustments to ozone aloft predictions are presented in Section IV.B; the effects of these corrections on EKMA results and documented in Section V.

D. Uncertainty Concerning Model Reactivity & Chemistry Assumptions

The current version of EKMA was developed for Los Angeles, which is dominated by auto exhaust. Auto exhaust tends to be more reactive than a combined mixture of stationary and mobile NMHC sources. A study conducted by Roy Weston, Inc. for the Texas Air Control Board concluded that "The underlying surrogate chemistry used in the EKMA model is too reactive, and is probably not suitable for simulating present and future ozone levels in the Houston Area" (Ref. 2). In Chicago, as in Houston, industrial source emissions dominate highway mobile source emissions by approximately 2:1.

Based upon a technique developed by Trigonis et al. (Ref. 3), IEPA evaluated the reactivity of the Chicago area NMHC emission and determined that the mixture in Chicago is less reactive than that assumed by the EKMA model. By varying the propylene/butane proportion that is input to the EKMA model, IEPA found that lowering the reactivity (i.e., increasing the butane fraction) produced EKMA model results that were, on average, closer to the observed peak ozone concentrations. However, as further described in Section IV.C., the effects of varying reactivity can also be addressed by proper choice of initial NMHC and NO_x concentrations. Although this procedure does not address the issue of how the model may internally perform under different levels of reactivity, it does produce results which avoid any need to make changes to USEPA's recommended reactivity inputs.

E. Inability of EKMA to Predict Peak Ozone Levels in Chicago

One of the EKMA modeling options is to run the model in the "calculate mode," using actual initial concentrations and known post 8:00 a.m. emission densities to calculate what the expected ozone level would be. In this way the modeled results can be compared with the observed ozone levels on a particular day.

IEPA has NMHC and NO_X data for July - September 1981. The IEPA took all of the "ozone conducive" days during this 1981 period and conducted a series of precision and accuracy tests of the EKMA model. In this series of comparisons, the IEPA ran the EKMA model approximately 260 times in the calculate mode and compared the results to observed ozone levels. In these comparisons the IEPA input actual mixing heights, various reactivity assumptions for the precursors, and ozone aloft using the federal default method (i.e., upwind monitoring). Accuracy and precision of the EKMA model in the calculate mode was weak in all cases. Where default reactivity was used, the model substantially overpredicted observed values. For example, the actual data had a mean peak ozone value of .079 ppm for the 20 days of simulation, while the EKMA model predicted a mean peak ozone level of 0.192 ppm, or 143% average overprediction. Correlation of the comparison was 0.20. The inability of the EKMA model to correlate well with observed ozone values suggests that the input data -- primarily NMHC and NO_X -- and mixing heights are not sufficiently accurate to produce useable results. Over-prediction suggests that reactivity, initial concentration, or mixing height data may be the source of the bias.

IV. Reevaluation of EKMA Model Inputs

A. $NMHC/NO_X$ Ratio

USEPA guidelines recommend using ambient monitoring data to determine the initial NMHC and NO_X concentrations, as well as the $NMHC/NO_X$ ratio that is used in the EKMA procedure (Ref. 1). USEPA conducted a study to determine the relationship between $NMHC/NO_X$ ratios calculated from monitored data as opposed to inventory derived ratios (Ref. 4). Because of the lack of correlation between the two methods, USEPA also recommended in that document that ambient measurements be used.

In the 1982 SIP submittal, IEPA used monitor-derived $NMHC/NO_X$ data. The data, collected over July - September 1981, suggested an average $NMHC/NO_X$ ratio of 7.2:1, which was consistent with the ratio used in the 1979 SIP. In the 1982 SIP, however, IEPA noted that the ratio varied considerably from day-to-day, and because no data was available for the actual high ozone days modeled, it recommended using a range of ratios that would encompass the variability of the data. This was necessary, since USEPA guidance indicated that if quality-assured $NMHC/NO_X$ data were not available, EKMA could not be used (Ref. 1).

In Chicago, the difference between an inventory derived $NMHC/NO_X$ ratio and the monitored ratio is almost a factor of two (3.71:1 compared to 7.2:1, respectively). This discrepancy can be attributed to one or more of the following:

a) Errors in the inventory;
b) Errors in monitoring instrumentation; and/or
c) non-representativeness of the monitored values with respect to regional emissions.

Errors in the inventory of this magnitude (i.e., a factor of two) are unlikely. Although errors associated with particular sources may be considerable, these errors tend to compensate each other when viewed in an aggragate sense. For example, although the 1979 and 1982 SIP inventories were developed independently, their ability to produce similar aggregate emission burdens is well within 5% for both the St. Louis and Chicago areas. NO_x emission are dominated by mobile sources and large industrial and utility fuel combustion sources for which reasonably accurate emission factors have been established, particulary in a relative sense. NMHC emissions are predominantly generated from fuel combustion and evaporative sources, where mass balance techniques are as accurate as the basic production data from which they are derived, which is also considered reasonably accurate, especially in a relative sense. Therefore, it is not expected that inventory derived estimates would be the cause of such a large discrepency. In addition, other aspects of the modeling procedure (emission fractions) and the demonstration of attainment must assume the veracity of this data to support an adequate plan.

Reliability of ambient NMHC and NO_x monitors has been subject to deserved scrutiny. Problems with NO_x data prompted IEPA to discard all continuous NOx data prior to 1981. However, audits performed in 1981 by USEPA showed that these instruments were, in general, operating with satisfactory performance.

In a report entitled, "Systems Audit of Air Monitoring Stations -- 1981 Non-Methane Organic Components Monitoring Study" (Ref. 5), the contractor noted that one the criteria for proper site location was "Remote from sources of oxides of nitrogen or hydrocarbons" (page 6). For the 160 North LaSalle site, the report notes that the site is in an area of high emission density and is surrounded by tall buildings, thus giving a "canyon effect".

A follow-up study by the same contractor (Ref. 6) conducted instrument performance audits on NMHC and NO_x monitors. The NMHC monitor located at 160 North LaSalle was rated excellent and satisfactory, respectively, for NMHC and methane measurements. No audit of the NO_x monitor was conducted. A second audit was conducted by the same contractor on 8/19/81 with the same overall results (Ref. 7 page 8). Discussions with IEPA Ambient Monitoring staff suggest that the continuous NO_x data collected in the summer of 1981 was, in their judgement, highly reliable.

To further investigate the source of the discrepancy in ambient vs. monitor derived NMHC/NO_X ratios, IEPA investigated the mobile source inventory, which, because of the placement of the monitor in an area of high mobile source strength, most substantially impact the monitor readings. The following describes how IEPA developed a "morning" mobile source gridded inventory to determine the changes in mobile source emissions by geographic area that may impact NMHC/NO_X ratios observed in the Chicago CBD.

Using the 1982 SIP mobile source inventory as a base, IEPA made adjustments to the input assumptions to reflect 6:00 - 9:00 a.m. mobile source emission conditions in the entire Chicago area. These input assumptions are summarized in Table 1.

TABLE 1

Mobile 2 Inputs Used to Determine Subregional NMHC/NO_X Ratios by CATS Ring.

Input Parameter	Arterials	Freeways
Evaluation Date	1981	1981
Average Vehicle Speeds:	Varies by zone; by peak, off-peak period	Varies by zone by peak, off-peak period
Ambient Soak Temperature:	75°F	75°F
Operating Mode Fractions: (Hot/Cold Start)	Ring specific hot/cold start %'s A.M. peak and off peak (see Table 2)	0.0/0.0/0.0
Vehicle Registration Distributions:	1980 passenger car Dist. from R.L. Polk	1980 passenger car Dist. from R.L. Polk
VMTMIX:	CATS arterial VMTMIX's for peak and off-peak (see Table 3)	CATS freeway VMTMIX's for peak and off-peak (see Table 3)

In the analysis, 6:00 - 9:00 a.m. emission of NMHC and NO_X are calculated by weighting the A.M. peak and off-peak emission factors by 1/3 peak and 2/3 off-peak.

The modification made to hot and cold start assumptions to replicate morning conditions are presented in Table 2.

TABLE 2

Operating Mode Fractions by Location and Time of Day (arterials).

A.M. Peak	Central Area	Sector 1	Balance of Inner Rings[1]	Outer Rings[2]
Non-Cat. Cold	10.0%	55.0%	73.0%	73.0%
Cat. Hot	55.0%	10.0%	5.0%	5.0%
Cat. Cold	10.0%	55.0%	75.0%	75.0%
A.M. Off-Peak Non-Cat. Cold	18.0%	18.0%	18.0%	16.0%
Cat. Hot	22.5%	22.5%	22.5%	33.0%
Cat. Cold	38.5%	38.5%	38.5%	41.0%

1. Rings 2-5
2. Rings 6-9

From: "Chicago Metropolitan Region Mobile Source Emission Inventory", David G. Gerard. IEPA/APC/ARAS 10/26/77.

VMT mixes used in the analysis were disaggragated by vehicle type and roadway type for both peak and off-peak conditions. The percentage splits used in each case were identical to those used in the 1982 SIP. These are summarized in Table 3.

TABLE 3

1980 VMT Mixes for Peak and Off-peak Periods.

	PEAK		OFF-PEAK		
Vehicle Type	Arterial	Freeway	Arterial	Freeway(N)[1]	Freeway (S)[2]
LDGV	86.9%	82.1%	78.3%	71.7%	60.7%
$LDGT_1$	5.4	4.3	6.9	7.3	5.8
$LDGT_2$	0.9	2.5	3.9	4.2	4.2
HDGT	1.8	2.3	4.5	4.1	10.1
LDDV	2.8	2.6	2.5	2.2	2.2
LDDT	0.2	0.1	0.1	0.1	0.1
HDDT	1.0	5.1	2.8	9.4	15.9
MC	1.0	1.0	1.0	1.0	1.0

1. Freeway(N) represents zones in Sectors 1-4
2. Freeway(S) represents zones in Sectors 5+

From: Table 7, CATS submittal

The results of analysis are presented in Table 4. The emissions summaries, which are expressed in units of Kg/day, as calculated at the CATS traffic zone level, using the "impedance" speed for each traffic zone as the speed input to the emissions generation model. Traffic zone emissions are then aggragated to emissions from each CATS traffic ring. Traffic rings are useful for transportation planning purposes, and are also well-suited in this analysis, because they originate with a small sector (i.e., Ring "0") in the Chicago CBD, which is also the location of the urban NMHC and NO_x monitors used to provide the initial concentration inputs to the EKMA model. Table 4 presents the morning NMHC/NO_x ratio for each ring and also presents the accumulative ratio if NMHC and NO_x emissions are respectively summed as one proceeds out from the Chicago CBD consecutively through Rings 1-9.

As can be seen from the table, Ring 0, the location of the 160 North LaSalle monitor, exhibits a mobile source NMHC/NO_x ratio of 11.0:1. This is primarily due to the extremely low average speeds encountered in the area (5-10 mph), which have the effect of increasing NMHC emissions and decreasing NO_x emissions. As one move out from Ring 0, average speeds increase, due to lower congestion on arterials and a higher percentage of freeway emissions.

Table 4
Morning Mobile Source Emissions by CATS Ring

Ring	THC	TNOx	Emission HC/NOx	Ambient Conc. HC/NOx	THC	TNOx	Emission HC/NOx	Ambient Conc. HC/NOx
0	261.86	75.42	3.5	11.0	261.86	75.42	3.5	11.0
1	1739.11	1339.63	1.3	4.1	2000.97	1415.05	1.4	4.5
2	2423.40	1788.47	1.4	4.3	4424.37	3203.52	1.4	4.4
3	3178.81	3153.23	1.0	3.2	7603.18	6356.75	1.2	3.8
4	2861.89	2843.70	1.0	3.2	10465.07	9200.45	1.1	3.6
5	3581.54	3941.23	.9	2.9	14046.61	13141.68	1.1	3.4
6	4925.07	5914.95	.8	2.6	18971.68	19056.63	1.0	3.2
7	6379.67	7647.00	.8	2.6	25351.35	26703.63	.9	3.0
8	2756.55	3804.92	.7	2.3	28107.90	30508.55	.9	2.9
9	1204.75	1964.81	.6	1.9	29312.65	32473.36	.9	2.9

1. Assumes weighting of 2 off-peak hour and 1 peak hour emissions during the 6-9 A.M. period.

2. Peak hour emissions assume A.M. peak hot/cold average speeds and VMT mix from CATS inventory.

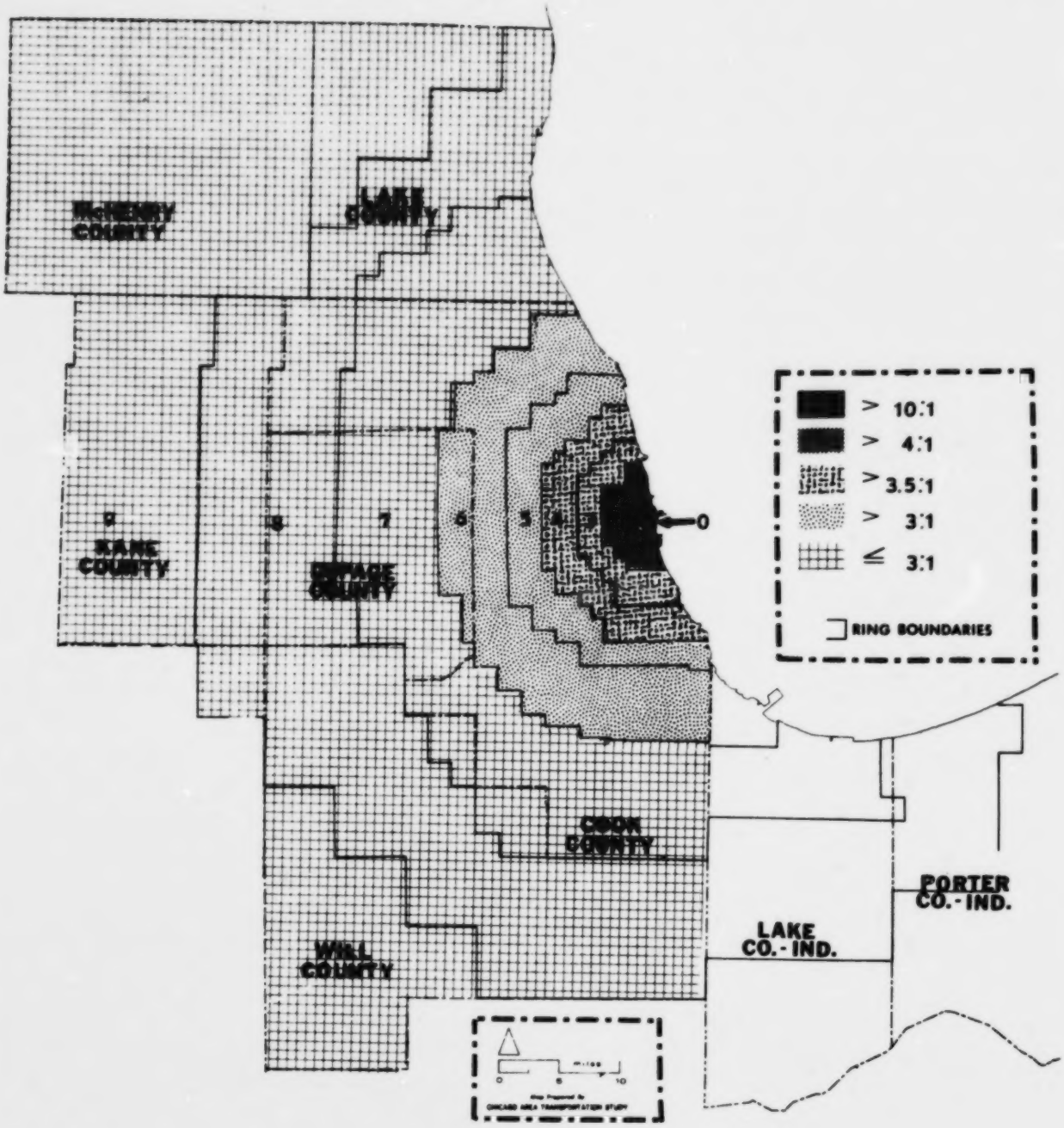
3. Off-peak emissions assume off-peak hot/cold, average speeds and VMT mix from CATS inventory.

4. Assume averaging results in an approximate 50/50 VMT split among peak and off-peak travel characteristics.

Table 4 also illustrates the extremely small contribution of Ring 0 emissions to the total pollutant burden. Ring 0 comprises only 5% of the total emission from Rings 0 and 1, which results in an average NMHC/NO_x ratio of 4.5:1, compared with 4.1:1 for Ring 1 taken by itself.. The relative significance of the emissions seen by the CBD monitor is further illustrated in Figure 3, which shows the spatial relationship of the traffic ring sectors. As seen from this figure, Ring 0 is not only small in terms of total emission burden, but is also geographically small, when compared to the extent of the urban area.

Figure 3

Accumulative Morning NMHC/NO_x Ratio from Mobile Sources by Traffic Ring



IEPA also had an NMHC and a continuous NO_X monitor at the Northwestern Medical School site, located at Huron and Fairbanks. This area is located in CATS traffic Ring 1. Data collected at this site from July 22 - September 30, 1981, indicated an average NMHC/NO_X ratio of 6.1:1. However, the federal USEPA audits of the NMHC instrument found its accuracy to vary from 5% underprediction to 31% overprediction. Overall, IEPA has determined that the monitor was overpredicting by 22%, yielding an adjusted average NMHC/NO_X ratio of 4.8:1. This compares with a morning mobile source generated ratio of 4.1:1 estimated for all of Ring 1.

Based upon the evaluation of monitored and emission inventory-generated NMHC/NO_X ratio data, the following conclusions are drawn.

1. When operated properly, NMHC and NO_X instruments can yield good monitoring data for use in an EKMA analysis.

2. The result of the monitored data collected in 1981, although highly variable, do compare favorably with emission inventory determined ratios; the CBD monitor recorded an average ratio of 7.2:1, whereas Ring 0 and Ring 1 exhibit ratios of 11.0:1 and 4.1:1; putting the monitor's ratio within the range of expected values. Results from the NWM monitor compared very favorably with inventory derived ratios.

3. The placement of the monitor at 160 North LaSalle is in an urban canyon, within 10 feet of strong NMHC and NO_X emission sources, making the monitor data sensitive to extremely localized conditions.

4. Although generally acceptable, monitor data produced under these localized effects will not yield an accurate area-wide NMHC/NO_X ratio; however the monitor can be used to substantiate ratios developed through other means.

5. Mobile source inventory NMHC/NO_X ratios, developed to simulate 6:00 A.M. - 9:00 A.M. conditions, show that the mobile source ratio ranges from 11.0:1 to 1.9:1, with the regional average morning mobile source NMHC/NO_X ratio equal to 2.9:1.

Developing an accurate NMHC/NO_X ratio is key to using the EKMA model with any degree of confidence. IEPA has evaluated monitored NMHC/NO_X and found that it agrees very well with mobile source emission patterns. Average morning mobile source NMHC/NO_X ratio is 2.9:1. However, mobile sources are not the only contributors to morning pollutant burden. Unfortunately, area and point source emission data are not available with hourly emission rates.

Because of the uncertainty in diurnal emission rates for total NMHC and NO_x, IEPA believes that the best estimate of a 1980 NMHC/NO_x ratio is 3.71, based upon total pollutant burden for the entire urban area, as calculated below:

1980 NMHC Inventory: 1,177,627 Kg/day
1981 NO_x Inventory: 1,006,271 Kg/day

$$\frac{1{,}177{,}627}{1{,}006{,}271} \times \frac{46 \text{ Kg/Kg-mole } NO_x}{14.5 \text{ Kg/Kg-mole NMHC}} = 3.71$$

Qualifications which should be considered in using this ratio are briefly discussed below:

1. The same ratio for just Cook County is 4.9:1, which is significantly higher than 3.7:1.

2. Mobile sources should be expected to predominate in the early morning, prior to regular hours of many businesses, suggesting a ratio closer to 2.9:1.

3. Morning NMHC/NO_x ratios are expected to be influenced by well mixed and diffuse carryover pollutants, especially under stagnation conditions that are typical of high ozone days.

For the reasons cited above, actual NMHC/NO_x ratio may reasonably be expected to be as low as 2.9:1 or as high as 4.9:1. However, the best estimate is that the most appropriate ratio lies somewhere in between. For this reason, and to avoid using a range of NMHC/NO_x ratios, the regional inventory value of 3.7:1 is selected for further analysis.

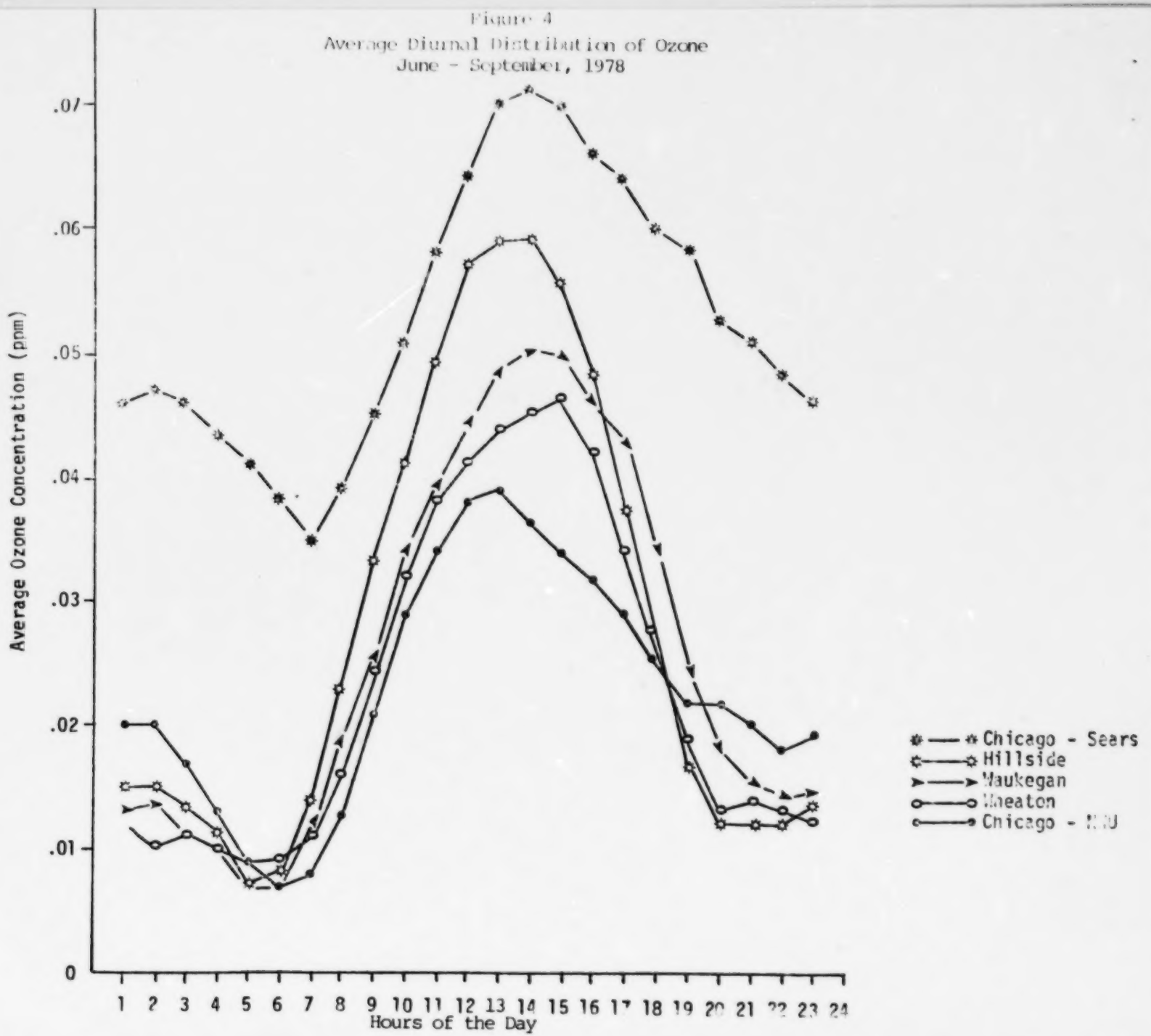
B. Sears Tower Ozone Aloft Study

In the 1982 SIP submittal, IEPA determined ozone aloft using the USEPA recommended procedure: 10:00 a.m. to 11:00 a.m. ozone levels at upwind monitors were averaged, and then averaged between the monitors (Elgin and Kankakee) to establish an ozone aloft value as input to the OZIPP model. Generally, high ozone aloft values will increase the amount of emissions reduction necessary to attain the O_3 NAAQS, based upon the model output. Therefore, an accurate representation of ozone aloft is necessary to produce accurate emission reduction estimates. However, ground level ozone monitored upwind from the urban core is only an estimation of ozone aloft. During 1978 and 1979 IEPA operated an ozone monitor at the top of the Sears Tower that recorded actual ozone aloft data. The following describes the analysis conducted by IEPA to use this data to develop a better estimate of ozone aloft for use in the EKMA procedure.

Average diurnal variation of ozone aloft at the Sears Tower for the summer of 1978 are depicted in Figure 4. From the figure, it is seen that ozone levels are relatively high during the early hours, decline as the morning progresses, and then rise rapidly at 7:00 a.m. to peak at 3:00 p.m. in the afternoon. The break point observed at 7:00 a.m. is due to solar heating, which has the dual effect of raising the mixing layer (thus mixing ozone aloft with lower concentrations of ozone and higher concentrations of precursors below) and the initiation of the photochemical process which produces higher ozone later in the day.

Figure 4

Average Diurnal Distribution of Ozone
June - September, 1978



Data sheets which depict ozone aloft data for all days monitored in 1978 and 1979 for the months of June, July and August are presented in Appendix A. The data sheets show the ozone values recorded at the Sears Tower at 3:00 a.m., 6:00 a.m. and 9:00 a.m., and corresponding data for the Kankakee and Elgin upwind sites taken at 10:00 a.m. and 11:00 a.m. on the same days. Also indicated are whether each day was judged "ozone conducive" (according to the definition of this term in Response Attachment 2) and, when available, the mixing heights recorded for those days. The Sears Tower monitor was located at approximately 1000 feet (300 meters) above local elevation. As seen from the data most of the recorded morning mixing heights were below 300 meters.

An attempt to correlate Sears Tower ozone aloft data with data recorded at the Kankakee and Elgin upwind sites produced uncertain results. The scatter plot of these data are presented in Figure 5. Although the goodness-of-fit is disappointing, the results tend to indicate that using upwind monitoring sites overestimates ozone aloft. IEPA proposes to use the regression line of this scatter plot to adjust ozone aloft measured at upwind sites to reflect a better estimate of true ozone aloft. This regression equation, in ppm, is:

O_3 (Aloft) = 0.022 + 0.42 x (Upwind O_3).

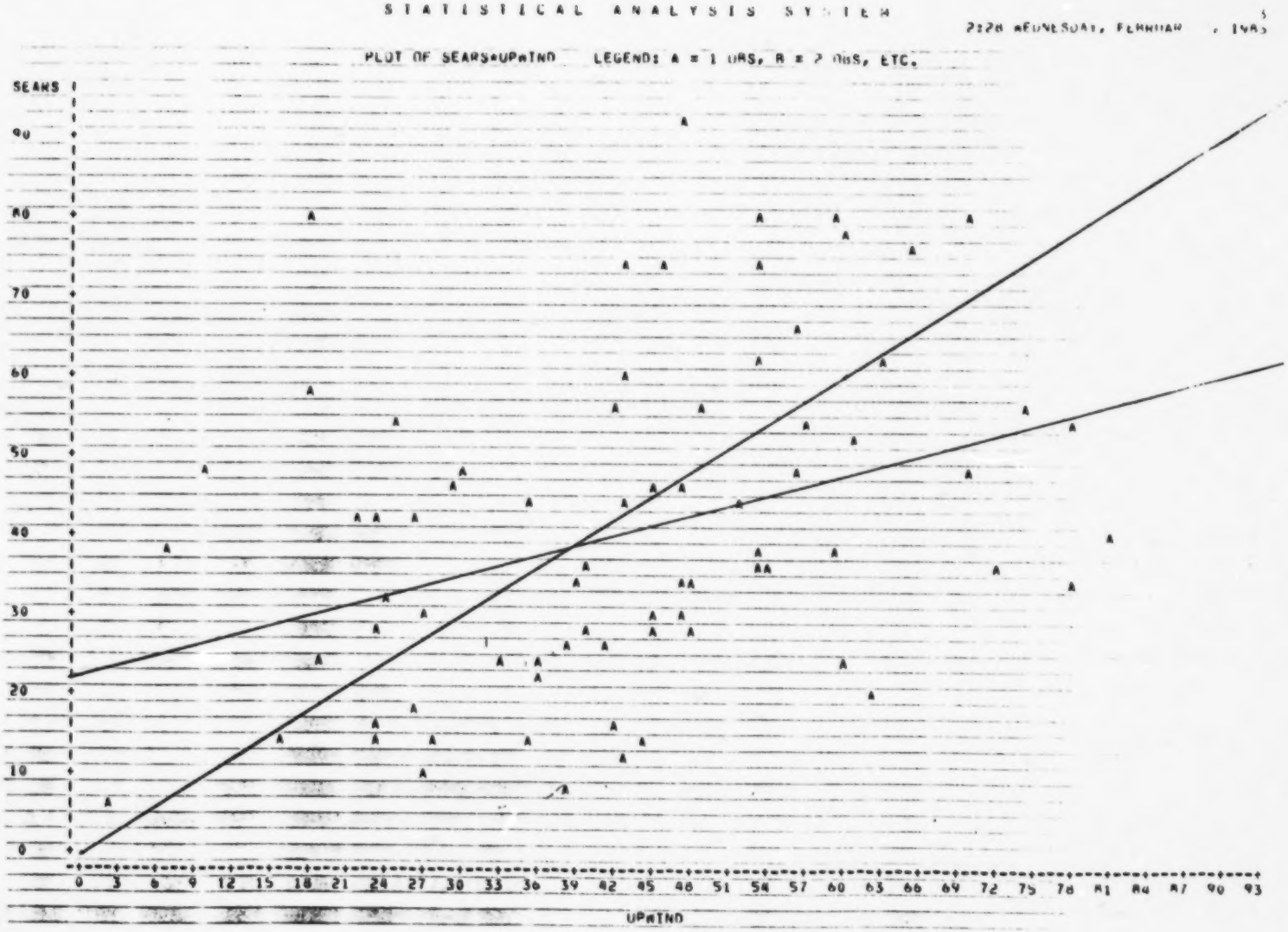

STATISTICAL ANALYSIS SYSTEM
PLOT OF SEARS*UPRIND LEGEND: A = 1 OBS, B = 2 OBS, ETC.
SEARS
90
80
70
60
50
40
30
20
10
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87 90 93
UPRIND

Figure 5

C. Improving EKMA Model Ability to Predict Peak Ozone Levels

The IEPA studied ozone conducive days during the 1981 period in which NMHC and NO_x data was available and ran the EKMA model in the calculate mode on each of those days. The EKMA model calculated ozone values that were, on average, more than twice the actual ozone values.

The IEPA took the actual data that had given a mean predicted ozone of 0.186 ppm versus an actual peak ozone of .079 and changed the minimum mixing height to 250 meters. Using actual mixing heights of less than 250 meters was not the cause of the EKMA model's overprediction, as the predicted mean ozone value using a 250 meter minimum mixing heghts was 0.192 ppm, a 143% over prediction. Next, the IEPA varied the model's chemical reactivity (percent propylene and aldehydes) in order to determine if the calculated peak ozone level could be made to more closely replicate the actual peak ozone levels. Lowering the percent propylene to 1% and keeping the percent aldehydes at 5% gave a mean peak ozone value of .095 ppm. Then the ozone aloft values were adjusted based on the Sears Tower regression line; one percent propylene was assumed, and the aldehydes were changed to 2%. The mean calculated peak ozone value then became .070 ppm versus an observed mean peak of .078 ppm.

Therefore, by adjusting the input chemistry to lower its reactivity, EKMA could be made to predict -- on average -- as close to average observed peak in any appreciable way improve the precision (i.e., correlation) of the analysis. In fact, the same results could be achieved the lowering initial concentrations rather than lowering reactivity. Although a cursory evaluation of reactivity in the Chicago NMHC mix indicated a lower reactivity than assumed by the model, the amount of the difference was less than suggested to be necessary by the comparison of calculate runs.

USEPA guidance discourages using chemistry assumptions different than the prescribed default inputs. This analysis indicates that variations of initial NMHC and NO_x concentrations have the same effect on predicting peak ozone levels as changes in chemistry. Therefore, no changes in chemistry assumption appears warranted as long as initial NMHC and NO_x concentrations can be adjusted to produce model results that replicate peak ozone levels. Because of the paucity and variability of monitored initial NMHC and NO_x concentrations, IEPA selected initial concentrations as the parameter to adjust to allow EKMA to accurately predict observed peak ozone concentrations. This procedure is more fully discussed in Section V.A.

V. Evaluation of EKMA Performance Using Modified Input Parameters

The acceptability of modifying inputs in the EKMA procedure must be based upon both the physical reasonableness of the proposed modifications, and whether the changes produce results that are closer to the observed conditions that the model is attempting to replicate. This section describes how IEPA evaluated the proposed modifications based upon a) 1981 ozone air quality data, and b) a comparison of ozone air quality changes which have occurred at Waukegan, Illinois from 1976 to 1980. Model inputs evaluated are:

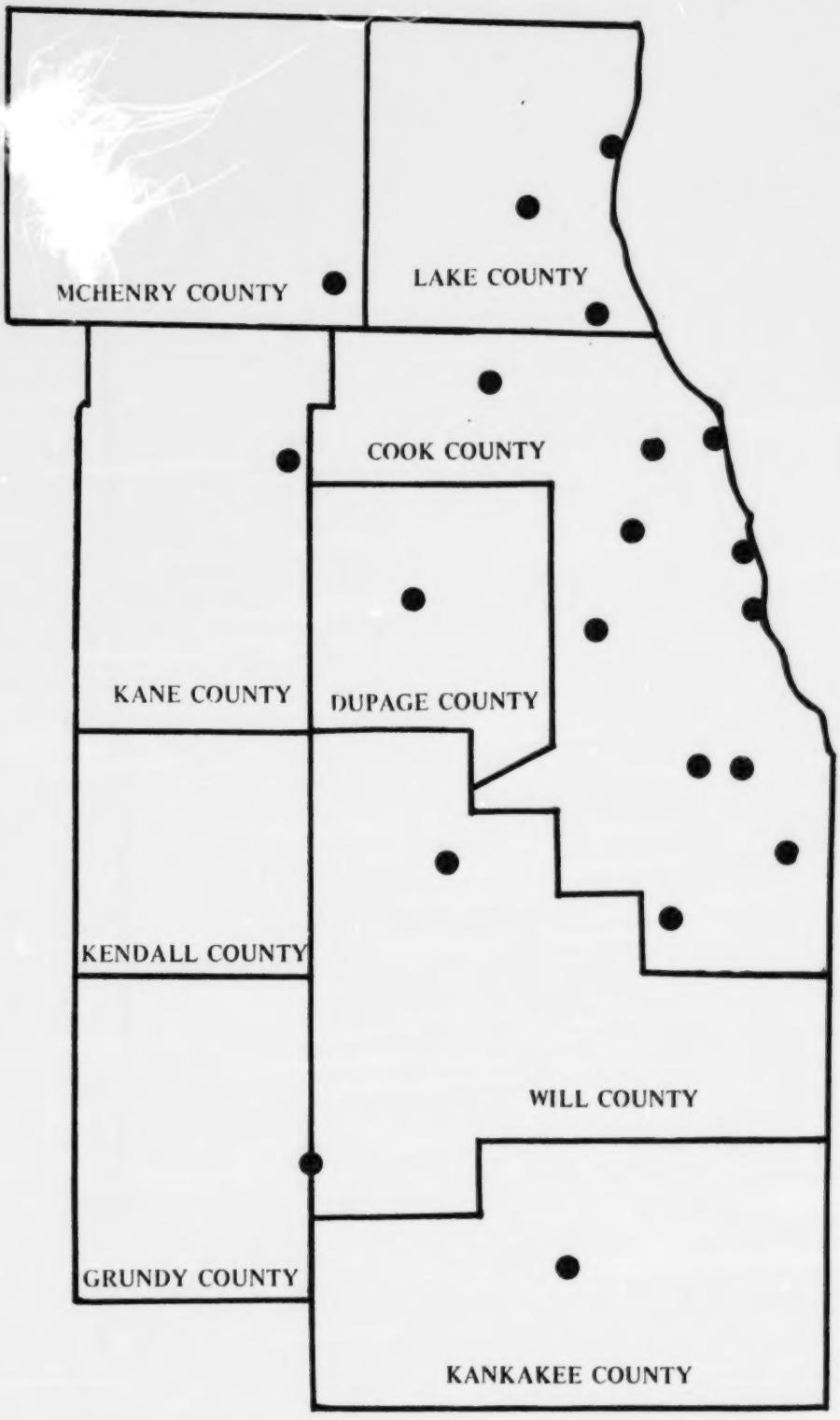
Ozone Aloft
$NMHC/NO_x$
Initial Mixing Height
OZIPP Calculate Time

A. Effect of Modified Inputs on EKMA's Ability to Accurately Predict Peak Ozone

As described in Section III.E, IEPA evaluated the ability of EKMA to predict observed peak ozone levels. Beginning July 22 in 1981, IEPA had NMHC and NO_x data at its monitor located in the Chicago urban area (160 North LaSalle Street). In developing a statistical model, IEPA developed a method for determining whether or not a day is conducive for ozone formation. Using only those days for which meteorlogical conditions were favorable for ozone formation, each day was modeled in the calculate mode with respect to the peak ozone level recorded in the region on that day. The total number of days used in the analysis was 20. The study region included the monitors located at Racine and Kenosha, Wisconsin, and all of the Illinois monitors depicted in Figure 6. Several variations of inputs were tested, which are described below:

FIGURE 6

1981 OZONE MONITORING NETWORK



Case I -- Actual 6-9:00 a.m. LDT initial NMHC and NO_x concentrations were used, as monitored at 160 North LaSalle. Per USEPA guidelines, a minimum morning mixing height of 250 meters was assumed. Ozone aloft was determined by averaging the upwind 10:00 - 11:00 a.m. morning ozone levels at the Kankakee and Elgin monitoring sites. Irrespective of the time of occurrence of the ozone peak, the simulation was allowed to continue 10 hours. Trajectories and emission fractions were specific to the monitoring site which recorded the peak ozone level for that day.

Case II -- The same inputs as Case I, except actual morning mixing heights were used. Where day-specific morning mixing height data was not availabe, 250m was assumed.

Case III -- The same inputs as Case II, but ozone aloft was determined by applying the adjustment described in Section IV B based upon the 1978-1979 Sears Tower data.

Case IV -- Same inputs as Case III, but NMHC and NO_x initial concentrations are corrected to reflect a 1981 inventory-determined ratio of 3.66:1. In relating this ratio to observed monitor readings, the NO_x concentration is assumed to be fixed, and the NMHC concentration is determined to be 3.66 times the NO_x concentration.

Case V -- Same inputs as Case IV, but the simulation is terminated at the time of observed peak ozone concentration.

The results of the analysis are presented in Table 5.

Table 5

Comparison of Observed Peak Ozone Concentrations with EKMA Predictions Under Various Input Assumptions 1981 Air Quality Data - Northeastern Illinois

				EKMH Predicted Peak				
			Observed Peak	Case I	Case II	Case III	Case IV	Case V
1.	7/23	Kenosha	67	255	255	255	179	179
2.	7/24	Libertyville	104	235	235	234	154	142
3.	8/11	Racine	200	468	468	201	172	149
4.	8/3	Racine	87	186	186	184	126	123
5.	8/4	Skokie	63	181	154	153	122	122
6.	8/5	Racine	66	151	157	158	146	146
7.	8/6	Kenosha	69	269	269	269	161	117
8.	8/7	Waukegan	33	240	240	241	164	138
9.	8/9	Kenosha	77	100	100	99	80	72
10.	8/10	Waukegan	41	219	205	211	140	105
11.	8/11	Kenosha	46	131	99	100	99	99
12.	8/12	Racine	53	115	93	96	75	69
13.	8/13	Kenosha	61	156	138	135	102	100
14.	8/14	Kenosha	46	278	278	279	158	135
15.	8/21	Kenosha	111	114	110	93	86	86
16.	8/22	Kenosha	107	75	75	71	94	89
17.	8/23	Kenosha	86	96	96	86	86	74
18.	8/24	Kenosha	136	135	133	128	114	112
19.	9/11	Racine	75	159	159	155	93	84
20.	9/14	Skokie	44	263	263	261	163	13
Mean			79	192	186	184	132	114
Slope			-	.696	.787	.728	.566	.684
Intercept			-	137	124	126	88	60
R			-	.20	.33	.30	.42	.53

Performance of any model is judged by its precision and accuracy. Precision is a measure of a models' ability to produce predictable results, which may be predictably higher or lower than observed values. Accuracy encompasses precision, but is further judged by ability to produce results that are comparable to observed values. By using simple linear regression, the correlation coefficient is a measure of precision; correlation and bias (e.g., zero intercept) taken together are a measure of accuracy. As depicted in the table summary statistics, correlation, or precision, is weak for all cases considered. In order to ensure a 90% probability that any correlation exists between variables, a correlation coefficient of 0.38 is required with 18 degrees of freedom (i.e., n=20). Only Cases IV and V meet this minimum test.

Accuracy is necessarily poor when precision is poor. However, accuracy of EKMA improves considerably as EKMA inputs are modified from Case I through Case V. In Case I EKMA overpredicts an average by 143%, and overpredicts by an average 44% in Case V.

As discussed in Section IV.C., IEPA also ran EKMA on these days with different reactivity assumptions. By changing the assumed propylene/butane split and percent aldehyde in the NMHC mixture, the average calculated ozone peaks could easily be brought into the range of the average observed values.

Although the correlation of the data is not strong, some inferences can be drawn that would explain the discrepancies between observed and modeled ozone values. First, it would appear that the pollutant mix assumed by the model is more reactive than actually exists in the Chicago region. This is supported by the tendency of the model to exhibit improved accuracy and precision as assumptions are modified to lower the apparent reactivity, or concentration, of the precursors. This is demonstrated by the assumptions which use actual mixing height instead of the USEPA-recommended minimum, the lowering of NMHC initial concentrations via the inventory-derived $NMHC/NO_x$ ratio, and termination the similation at the time of the peak. The physical support for these adjustments is the low percentage of highway mobile source emissions (approximately 34%) as compared to the model assumption (i.e., 100%). Precision is no doubt influenced by the lake breeze, which is not considered in the simplified box model approach and which tends to have a greater effect on monitors located near the lake (lakeside monitors located at Waukegan, Kenosha and Racine account for 17 of the 20 days modeled).

The only input change that does not significantly improve accuracy or precision is the modified ozone aloft assumption. This is probably due to the marginal impact of the adjusted ozone aloft value as compared to the USEPA recommended default method, and the tendency of the adjustment to either raise or lower the ozone aloft input, depending on the value observed at the upwind monitors (i.e., it raised peak values in 6 cases, decreased it in 12, and did not change it in 2 cases).

Scatter plots of the data analyzed in Case I, Case IV and Case V are presented in Figures 7, 8 and 9. Although the "shotgun" appearance of the data is apparent in all cases, it is also apparent that the modified inputs represented by Cases IV and V significantly close the scatter, and bring the bound of the data closer to observed conditions. Scatter and bias can be eliminated completely by choice of the appropriate NMHC and NO_x concentrations which "force" the model to calculate the observed ozone concentrations.

Figure 7

Predicted Versus Observed Daily Peak Ozone on Conducive Days
in July - September, 1981

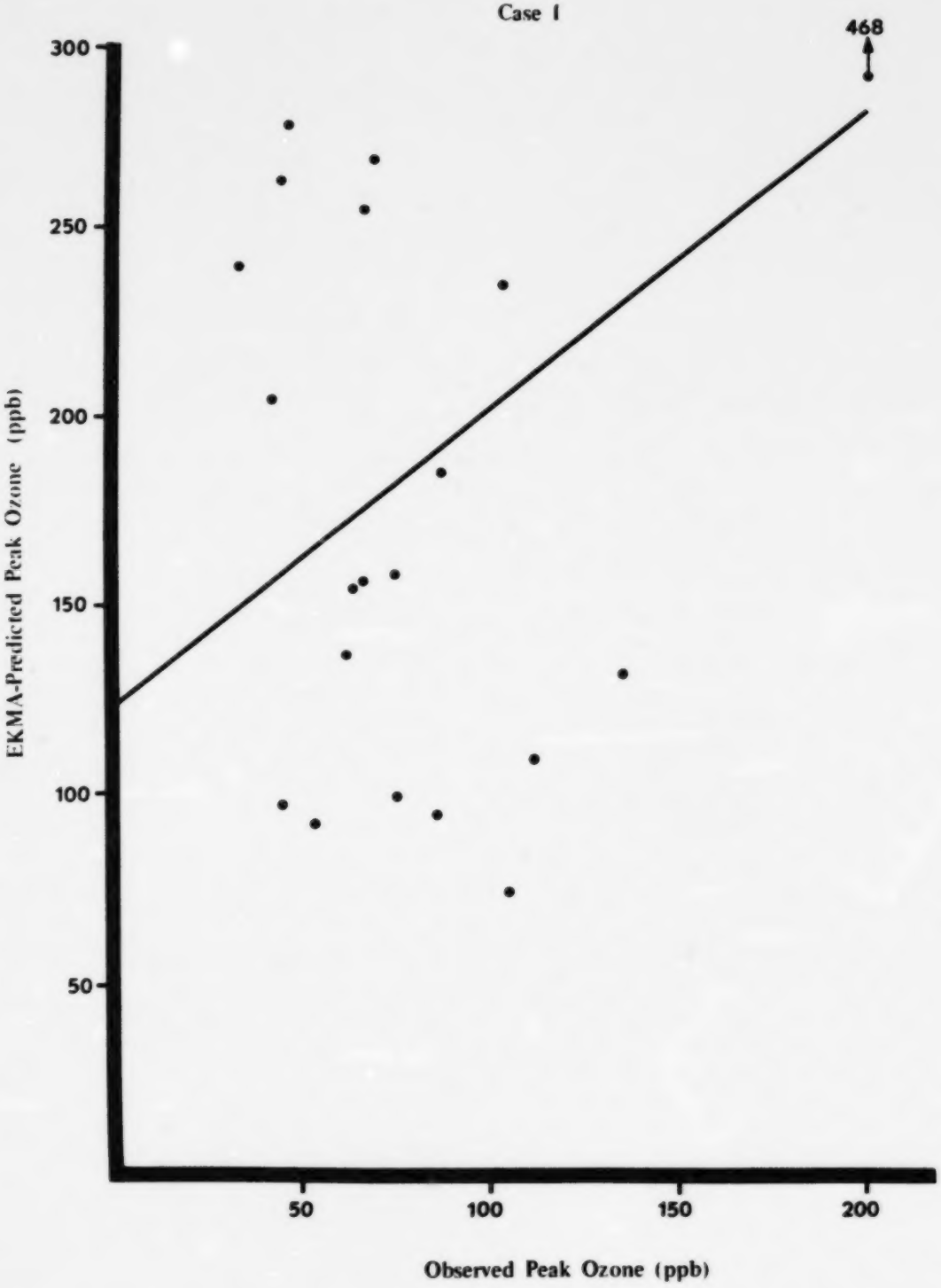


Figure 8

Predicted Versus Observed Daily Peak Ozone on Conducive Days in July - September, 1981

Case IV

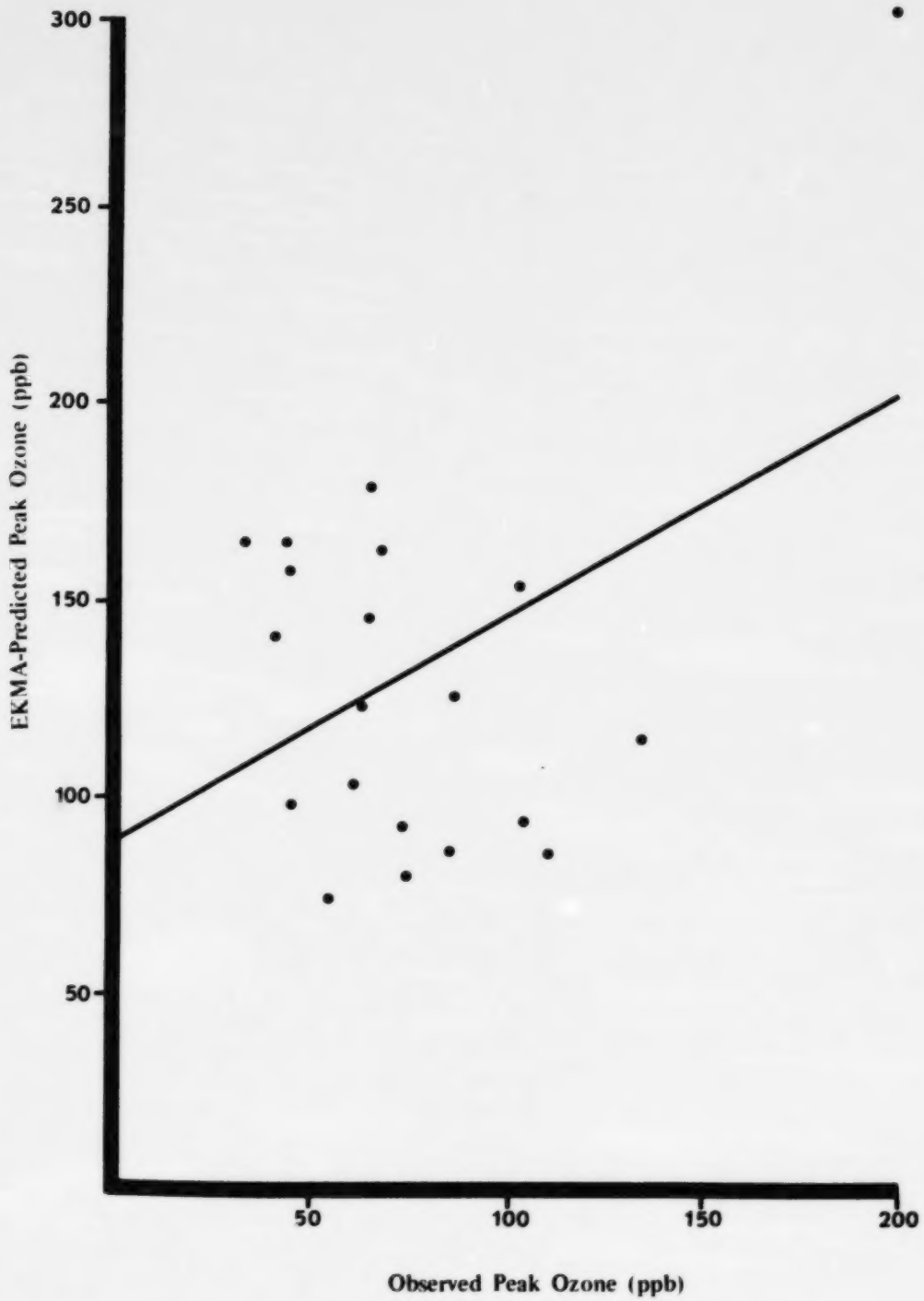
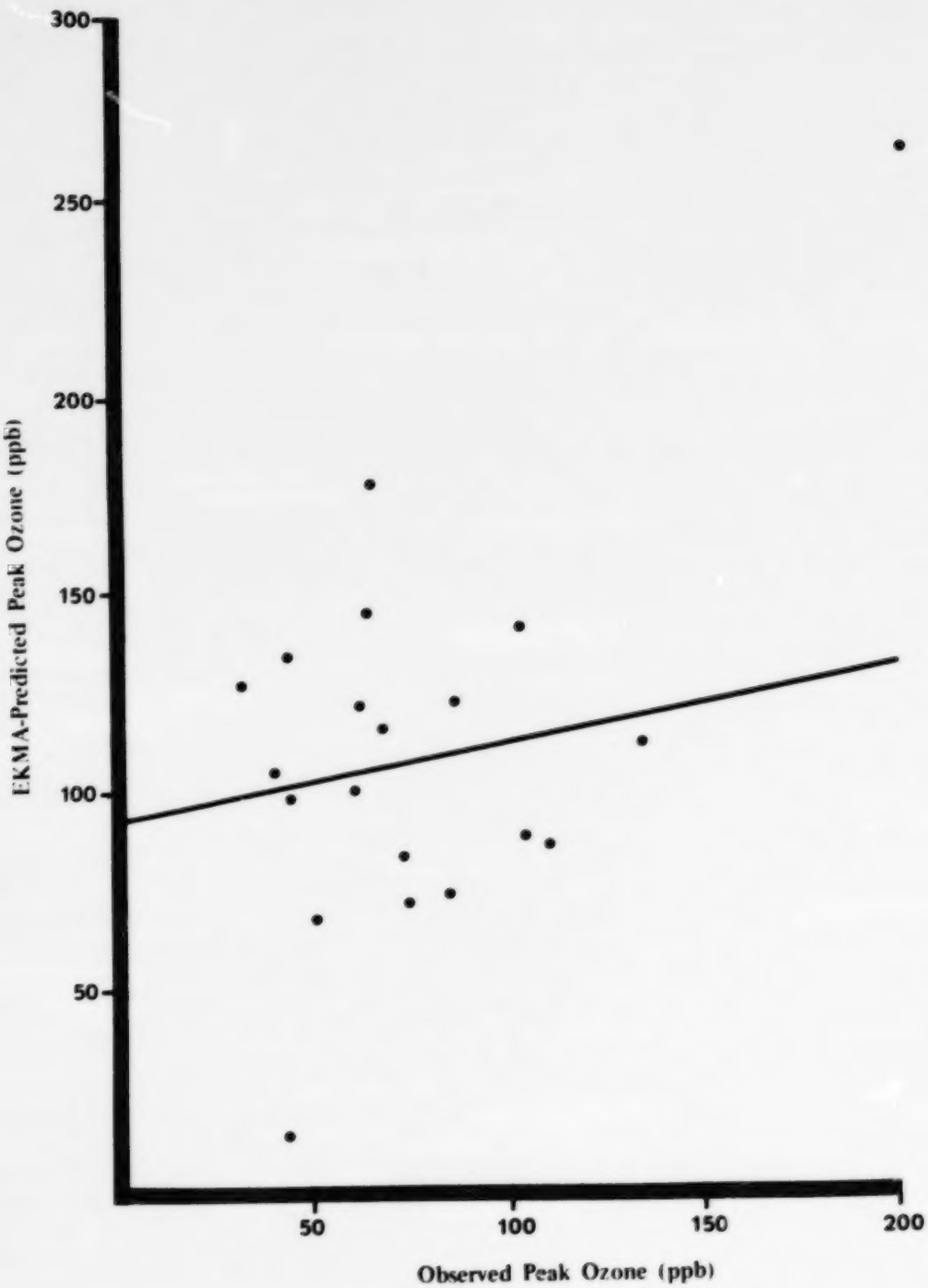


Figure 9

Predicted Versus Observed Daily Peak Ozone on Conducive Days
in July - September, 1981

Case V



B. Effect of Modified Inputs on Waukegan Modeling Discrepancy

A completely separate test of whether or not the modifications suggested above are reasonable in terms of actual observed air quality characteristics is to apply the proposed changes to actual design-day circumstances to determine if the inputs can produce EKMA results that are more in keeping with observed air quality trends. This is facilitated by using the air quality data at Waukegan, Illinois, which was found to be the controlling monitor in development of both the 1979 and the 1982 SIPs for the northeastern Illinois study area (i.e., exclusive of southeastern Wisconsin). In the 1979 SIP, the design day was August 21, 1976 (0.241 ppm), in the 1982 SIP, the design day was August 29, 1980 (0.143 ppm). Input values used for these two EKMA runs are presented in Table 6:

Table 6
EKMA Inputs for the Waukegan
1976-1980 Comparison Analysis

Input Parameter	1976	1980[1]	1980[2]
Initial Concentration (ppm)			
NMHC	5.10	4.26	4.08
NO_x	1.06	1.15	1.15
Time Zone	6	6	6
Date	August 21	August 29	August 29
Time (LDT)	800-1400	800-1400	800-1400
Solar Noon	1200	1300	1300
Mixing Heights (meters)			
Morning	250	250	250
Afternoon	1750	1750	1750
Time	800-1538	800-1530	800-1530
Propylene Fraction	0.25	0.25	0.25
Aldehyde Fraction	0.05	0.05	0.05
Ozone Aloft (ppm)	0.051	0.051	0.051
Emission Fractions (NMHC)			
Hour 1	0.022	0.022	0.022
Hour 2	0.022	0.022	0.022
Hour 3	0.022	0.022	0.022
Hour 4	0.022	0.022	0.022
Hour 5	0.004	0.004	0.004
Hour 6	0.004	0.004	0.004

Input Parameter	1976	1980[1]	1980[2]
Emission Fractions (NO_x)			
Hour 1	0.016	0.016	0.016
Hour 2	0.016	0.016	0.016
Hour 3	0.016	0.016	0.016
Hour 4	0.016	0.016	0.016
Hour 5	0.006	0.006	0.006
Hour 6	0.006	0.006	0.006
Calculated Ozone Peak (ppm)	0.241	0.157	0.143

1. Assumes 1980 inventory NMHC and NO_x concentrations
2. Assumes 1980 inventory NO_x concentration and a NMHC concentration that results in the observed ozone peak of 0.143 ppm.

$NMHC/NO_x$ ratios were derived from region-wide inventory data. As discussed in Section IV.A., the ratio for 1980 was determined to be 3.71:1. For 1976, the ratio was developed as follows: NMHC for 1976 was extrapolated back from 1979 SIP data for the base year of 1977, assuming that stationary source emissions were unchanged and that mobile source emissions were proportionately the same as the change in mobile source emissions from 1977 - 1978, or

$$(1976T) = (1977T) - (1977M) + \frac{(1977M)^2}{(1978M)}$$

$$= 563{,}787 \text{ Tons/years, where}$$

1976T = 1976 total NMHC inventory
1977T = 1977 total NMHC inventory
1977M = 1977 mobile source NMHC inventory
1978M = 1978 mobile source NMHC inventory

NO_x emissions were only available for Cook County in the 1979 SIP. NO_x emissions for 1976 were extrapolated from 1977 NO_x emissions by assuming the same proportional change from 1976 - 1977 as from 1977 to 1978, and that the geographic split of NO_x emissions did not change from 1976 to 1980:

$$1976T = \frac{(1977TC)^2}{(1978TC)} \times \frac{(1980TR)}{(1980TC)}$$

$$= 371280 \text{ T/yr}$$

1976T = 1976 total NO_x inventory
1977TC = 1977 total emissions in Cook County
1978TC = 1978 total emissions in Cook County
1980TC = 1980 total emissions in Cook County
1980TR = 1980 total regional NO_x emissions

Using these estimates of a 1976 inventory, an $NMHC/NO_x$ ratio of 4.8:1 is established for the base case. Ozone aloft is determined from the procedure described in Section IV.B. Initial NMHC and NO_x

concentrations are selected which force the model to predict a 0.241 ppm at the peak hour. Because of the extremely low mixing height used in the base case, the default value of 250 meters is used for both the 1976 and 1980 cases. The alternative is to use an NMHC initial concentration of 10 ppm or more, which is unrealistically high. Emission fractions are such that, when multiplied by the initial concentration, they yield post 8:00 a.m. concentration that would result from the estimated 1976 NMHC and NO_x inventories, geographically distributed as determined in the 1982 SIP inventory.

Once these model inputs are adjusted to predict the peak ozone concentration accurately, NMHC and NO_x initial concentrations are scaled back to reflect inventory changes that occurred from 1976 to 1980. Emission fractions are held constant, which has the effect of lowering post 8:00 A.M. emissions by the same proportions or initial concentrations. The 1980 run uses August 29 as the day of year, and also assumes a 250 meter morning mixing height. The resulting EKMA peak ozone level is 0.157 ppm, as compared to an observed peak level of 0.143 ppm. To compare these results with the earlier evaluation using unchanged EKMA inputs, NMHC initial concentration is reduced until a calculated 0.143 ppm is achieved, which is the peak ozone observed on the design day in question. This model run shows that NMHC emissions would have to be reduced 20 percent to produce the decrease in ozone levels observed at Waukegan from 1976 to 1980, as compared to 16% reduction that actually occurred.

This discrepancy is small enough that its cause can be attributable to errors in inventory, calibration changes, and/or uncertainty in mixing height inputs. In any case, the inputs selected have reduced the discrepancy by a considerable amount, and support the choice of using the modified model inputs.

In summary, IEPA has proposed to modify certain EKMA model inputs based upon the better supportability of these inputs in a physical sense: The NMHC/NO_x ratio is based upon known inventory emission rates that have been validated with air quality data; ozone aloft data has been adjusted to reflect area-specific ozone aloft observations, and simulation times reflect actual times of peak occurrences.

By using these procedures on air quality data available in 1981, and in a comparison of Waukegan 1976 and 1980 air quality data, the ability of the EKMA model to predict peak ozone values is greatly improved, and its ability to track changes in ozone air quality in northeastern Illinois is made consistent with observed trends.

In the following Section, the revised air quality analysis is conducted to determine the amount of NMHC reduction that is necessary to achieve the ozone NAAQS in northeastern Illinois and southeastern Wisconsin using these inputs.

VI. Determination of Emission Reduction Requirements

To determine emission reduction requirements, IEPA used EKMA in two separate cases: Case I is establishing a control requirement using only the air quality data from northeastern Illinois, and Case II utilizes the additional ozone air quality monitors located in Racine and Kenosha, Wisconsin, as downwind sites.

Case I -- Emission Reduction Requirements Based Upon Northeastern Illinois Ozone Monitors

From the EKMA analyses conducted in the original 1982 SIP, Waukegan, Illinois, was found to be the design site. The five highest ozone days at Waukegan for the period 1979-1981 were evaluated using the EKMA isopleth package for each day. All runs utilized a ten hour simulation and 250 meters was assumed to be the minimum morning mixing height. The input data used to make these simulations and the resulting control requirements are presented in Table 7.

Table 7

Summary Listing of Input Data Used In OZIPP Screening Runs For Generating
Chicago City-Specific EKMA Isopleth Diagrams
Assumed 3.7-1 HC/NO_x Ratio 1.158 HC .312 NO_x

Run No.	Ozone Design Value (ppm)	Date	Time Of Violation (LDT)	Mixing[2] Height am	Mixing[2] Height pm	Current[3] Transport/ Background (ppm)	Future[4] Transport/ Background (ppm)	Relative Emission Rates[5] Chicago VOC	Chicago NOx	Lake VOC	Lake NOx	HC Control Requirements
Waukegan 1	.186	07/21/79	1600	250m	1804m	.058	.055	.081	.061	.016	.022	38.8%
Waukegan 2	.172	08/01/81	1400	575m	1172m	.049	NA	.035	.027	.007	.009	40.0%
Waukegan 3	.158	07/10/79	1500	250m	2077m	.048	NA	.081	.061	.016	.022	26.4%
Waukegan 4	.143	08/29/80	1600	250m	2043m	.054	.052	.081	.061	.016	.022	24.2%
Waukegan 5	.139	08/26/80	1500	250m	1705m	.052	.051	.081	.061	.016	.022	23.0%

1. Source: USEPA guideline for interpretation of ozone air quality standards

2. Source: National Climate Center radiosonde data based on Peoria airport upper air soundings.

3. Source: IEPA/DAPC analysis of upwind ambient ozone data. 1100-1300 (LDT) average ozone concentration measured at upwind sites.

4. Source: USEPA guidelines. Future value assumed to be reduced in proportion to the expected VOC emission reductions projected assuming a national mix of growth estimates, anticipated impact of RACT and the impact of the FMVCP.

5. Source: USEPA guideline for use of city-specific EKMA in preparing ozone SIPS.

From Table 7 it is seen that Waukegan 4 (i.e., 8/29/80, 0.143 ppm) is the fourth highest, or design day. Once this day was selected, EKMA was rerun in the calculate mode to determine both emission reduction requirements and the year of attainment. In this analysis, initial NMHC and NO_x concentrations were selected that allowed the model to predict the observed peak ozone level at the time of the peak. It was again assumed that 250 meters was the minimum mixing height. EKMA calculate runs were conducted for each year from 1980 through 1987 with the changes in NMHC and NO_x emissions that are expected to occur each year. In addition, calculate runs were made for 1986 and 1987 which further assume implementation of a contingency plan or both a contingency plan and a vehicle I/M program. The results of this analysis are presented in Table 8. As seen from the analysis, attainment is expected in mid-1983, with a required emission reduction of something less than 19%. As explained in the SIP, attainment by mid-1983 is tantamount to attainment by December 31, 1982, because of the timing of control requirement implementation and climatological factors.

Table 8

Chicago Urban Area Design Day Predicted Ozone Levels
Determined by the EKMA Model Calculate Mode
Waukegan, Illinois
August 29, 1980

Year	Initial nMOC (ppm)			Initial NO_x (ppm)	nMOC/NO_x Ratio			Predicted Ozone Level Proposed Plan	Contingency Plan	I/M
	A	B	C		A	B	C			
1980	2.245			.605	3.71-1			.143		
1981	2.128			.581	3.66-1			.138		
1982	2.029			.557	3.64-1			.134		
1983	1.816			.532	3.41-1			.121		
1984	1.666			.508	3.28-1			.113		
1985	1.612	1.545		.484	3.32-1	3.19:1		.113	.107	
1986	1.509	1.423	1.351	.460	3.27-1	3.04-1	2.93-1	.109	.101	.094
1987	1.475	1.390	1.307	.436	3.38-1	3.19-1	3.00-1	.110	.103	.095

Column A represents emission and ozone changes with the proposed plan.

Column B represents emission and ozone changes with the proposed plan and the contingency plan.

Column C represents emission and ozone changes with the proposed plan, the contingency plan, and I/M.

Case 2 -- Emission Reduction Requirements Based Upon Southeastern Wisconsin Ozone Monitors

In a manner similar to that used at the Waukegan site, air quality data for Racine and Kenosha were examined to select the five potential design days at each site. For this analysis, the EKMA procedure was used in the isopleth mode with a minimum mixing height of 250 meters, and the NMHC and NO_x initial concentrations depicted in Table 9. Ozone aloft was determined as described in Sectin IV.B., and future ozone aloft was determined based upon the USEPA suggested procedure.

Table 9

Summary Listing of Input Data Used In OZIPP Screening Runs For Generating
Chicago City-Specific EKMA Isopleth Diagrams - Southern Wisconsin Air Quality Data
Assumed 3.7-1 HC/NO_x Ratio 1.158 HC .312 NO_x

Run No.	Ozone Design Value (ppm)	Date	Time Of Violation (LDT)	Mixing[2] Height am	Mixing[2] Height pm	Current[3] Transport/ Background (ppm)	Future[4] Transport/ Background (ppm)	Relative Emission Rates[5] (Kg/Km^2-hr) Cook VOC	Cook NOx	Lake VOC	Lake NOx	Kenosha VOC	Kenosha NOx	Racine VOC	Racine NOx	HC Control Requirements
Racine 1	.201	07/21/79	1900	250m	1804m	.058	.055	.081	.061	.016	.022	.012	.018	.007	.006	41.0%
Racine 2	.200	08/01/81	1500	575m	1172m	.049	NA	.035	.027	.007	.009	.005	.008	.003	.002	46.7%
Racine 3	.181	07/18/81	1500	331m	1632m	.048	NA	.061	.046	.012	.016	.009	.014	.005	.004	42.5%
Racine 4	.174	07/10/79	1700	250m	2077m	.056	.054	.081	.061	.016	.022	.012	.018	.007	.006	33.7%
Racine 5	.170	08/26/80	1600	250m	1705m	.052	.051	.081	.061	.016	.022	.012	.018	.077	.006	36.5%
Kenosha 1	.258	07/21/79	1800	250m	1804m	.058	.055	.081	.061	.016	.022	.012	.018			47.1%
Kenosha 2	.209	07/10/79	1600	250m	2077m	.056	.054	.081	.061	.016	.022	.012	.018			43.8%
Kenosha 3	.198	08/01/81	1500	575m	1172m	.049	NA	.035	.027	.007	.009	.005	.008			45.5%
Kenosha 4	.177	07/11/79	1400	250m	932m	.049	NA	.081	.061	.016	.022	.012	.018			37.0%
Kenosha 5	.167	07/27/79	1500	250m	1525m	.036	NA	.081	.061	.016	.022	.012	.018			31.1%

1. Source: USEPA guideline for interpretation of ozone air quality standards

2. Source: National Climate Center radiosonde data based on Peoria airport upper air soundings.

3. Source: IEPA/DAPC analysis of upwind ambient ozone data. 1100-1300 (LDT) average ozone concentration measured at upwind sites.

4. Source: USEPA guidelines. Future value assumed to be reduced in proportion to the expected VOC emission reductions projected assuming a national mix of growth estimates, anticipated impact of RACT and the impact of the FMVCP.

5. Source: USEPA guideline for use of city-specific EKMA in preparing ozone SIPS.

The results of this analysis indicate that Kenosha 4 (July 11, 1979; 0.177 ppm) is the design day to use in determining emission control requirements. Initial NMHC and NO_x concentrations were selected which resulted in EKMA predicting the peak concentration -- 0.177 ppm at the time of peak occurrence -- 1400 hours, local daylight time. Because the design value occurred in 1979, the ratio of initial concentrations was selected to represent the inventory derived ratio for NMHC/NO_x that represents the ratio calculated for 1979. Emission fractions were adjusted to reflect actual post 8:00 A.M. emissions based upon inventory data.

Initial concentrations and post 8:00 A.M. emissions were then reduced by the percentage reductions indicated in the 1982 SIP inventory, except the reduction from 1979-1980, which was taken from the 1979 SIP inventory. The results of the analysis are summarized in Table 10, which shows the expected air quality improvement from 1979 to 1987 with the proposed program, and for 1985-1987, with the added benefits of contingency measures and a vehicle inspection and maintenance program. From this table, it is seen that attainment is expected by 1984 with the current program only. Yearly changes of emissions from 1979-1987 for the aggregate of sources in Lake and Porter Counties, Indiana, and Kenosha and Racine Counties, Wisconsin, are assumed to be proportionately the same as Illinois. This assumption is necessary because of the lack of year-specific emission inventories for these areas. However, it is the best judgment of IEPA that this assumption is sound because of the similarity of expected emissions reduction profiles of these areas, and the preponderance of emissions from Illinois when compared to these areas.

Table 10

Southeast Wisconsin Area Design Day Predicted Ozone Levels
Determined by the EKMA Model Calculated Mode
Kenosha, Wisconsin
July 11, 1979

Year	Initial nMOC (ppm)			Initial NO_x (ppm)	nMOC/NO_x Ratio			Predicted Ozone Level Proposed Plan	Contingency Plan	I/M
	A	B	C		A	B	C			
1979	1.73			.443	3.9-1			.176		
1980	1.59			.429	3.71-1			.159		
1981	1.51			.412	3.66-1			.152		
1982	1.44			.395	3.64-1			.148		
1983	1.29			.377	3.42-1			.129		
1984	1.18			.360	3.28-1			.117		
1985	1.14	1.08		.343	3.32-1	3.15-1		.117	.106	
1986	1.07	1.01	.957	.326	3.28-1	3.10-1	2.94-1	.112	.101	.091
1987	1.04	.984	.925	.309	3.37-1	3.18-1	2.99-1	.114	.104	.092

Column A represents emission and ozone changes with the proposed plan.

Column B represents emission and ozone changes with the proposed plan and the contingency plan.

Column C represents emission and ozone changes with the proposed plan, the contingency plan, and I/M.

VII. Verification of EKMA Results

The EKMA results determined in Section VI. above are based on changes to EKMA inputs that were documented in Section IV and evaluated in Section V. This section analyzes the resulting control requirements to determine if they are supportable based upon independent comparisons. The methods available are: a) To evaluate the emission control requirements determined here with a completely independent determination of emission control requirements -- the statistical analysis, and b) a comparison of air quality trends since the 1979-1980 time period with the EKMA-predicted air quality levels.

Comparison With the Statistical Analysis

The statistical analysis to determine emission control requirements is documented in Attachment 2 to this comment response. Table 11 below presents the results of comparing the EKMA derived control requirements with that those determined by the statistical analysis. For this comparison, 0.124 ppm is assumed to represent attainment, as all of the data used in the statistical approach also utilizes this assumption.

Table 11

Comparison of NMHC Emission Control
Requirements from EKMA and the Statistical Approach

	Waukegan	Kenosha
EKMA	17%	22%
Statistical Approach	16%	26%

As seen from Table 11, the results of the EKMA and statistical analysis are within 1% for the Illinois only analysis, and within 4% for the analysis that includes southeastern Wisconsin.

Comparison of EKMA Model Prediction with Post 1979-1980 Monitored Ozone Air Quality.

As presented in Tables 8 and 10, EKMA, when used in the calculate mode, can be used to predict future air quality based upon expected emission inventory changes of NMHC and NO_x, and assuming similar day-specific EKMA inputs. In this comparison, the yearly second high value is used, as this is the value one would use if considering only one year of air quality data in an EKMA analysis. However, the monitored EKMA "design" value is also compared with the highest one hour reading in each of the years for the two monitors.

Table 12

Comparison of Monitored vs. EKMA Predicted
Ozone Air Quality and Percent Difference (%)

	EKMA	Waukegan Monitored 2nd High Value		Monitored High Value	
1980	0.143	0.139	(-3%)	0.143	(0%)
1981	0.136	0.133	(-4%)	0.173	(+25%)
1982	0.134	0.114	(-15%)	0.113	(-13%)
Mean	0.138	0.129	(-7%)	0.144	(+5%)
		Kenosha			
1979	0.177	0.209	(+18%)	0.258	(+46%)
1980	0.159	0.129	(-19%)	0.163	(+3%)
1981	0.152	0.151	(-1%)	0.198	(+30%)
1982	0.148	0.104	(-30%)	0.118	(-20%)
Mean	0.159	0.148	(-7%)	0.184	(+16%)

As seen from Table 12, the actual air quality levels are, on average, less than the EKMA predicted air quality levels when using the second-high day for both the Waukegan and Kenosha monitors. (A more technically correct comparison would be to use the 2nd high value observed at Waukegan and Kenosha in 1980 and 1979, respectively, as the EKMA design value. However, selecting such a value would not be in accordance with USEPA policy on selecting an EKMA design value.) From the table, it is seen that the mean EKMA predicted air quality levels are between the high and second-high values for both Waukegan and Kenosha, with the EKMA procedure predicting higher air quality levels in 1982 than observed at either site, when compared with 2nd high or high days. From this comparison, it is concluded that this EKMA analysis is not underestimating projected air quality levels, and subsequently, not underestimating emission control requirements, as they have thus far been demonstrated for 1981 and 1982.

VIII. Qualifications on Revised EKMA Analysis and Summary of Conclusions

A. Reactivity

Even though the IEPA has adopted a "best estimate" of emission control requirements which appears supportable, achieving these results requires "forcing" the model to predict ozone values under initial concentration assumption that may be unrealistic. The EKMA model chemistry is based on an NMHC mix dominated by automobile exhaust. It is highly unlikely that this reactivity reflects cities such as Chicago, that are dominated by stationary sources. However, until reactivity issues are resolved, the model must be run with inputs that compensate for any errors in reactivity assumptions. IEPA believes this methodology is consistent with USEPA guidance on this subject, as stated in the December 3, 1981 Rhodes memorandum (Ref. 8).

B. Ozone Aloft

Although the Sears Tower information allows the IEPA to use surface ozone data to more accurately reflect actual ozone aloft levels, the adjustments are still approximations and subject to either underestimating or overestimating the actual ozone aloft. Since the ozone aloft input is one of the key inputs to the model, the uncertainty associated with its determination should be recognized.

C. NMHC/NO_x Ratio and Ambient Concentrations

The IEPA has used both the emission inventory and monitored data to establish the NMHC/NO_x ratio for Chicago. Although this was done to reduce uncertainty of the most important input to the model, it is subject to uncertainties inherent in emissions and monitored data. In addition, keying on developing an accurate ratio requires that initial concentrations used in the analysis be determined from the ratio, and not vise versa. This problem is mitigated by the EKMA isopleth process, which downplays the importance of initial concentrations with respect to NMHC/NO_x ratio, and USEPA guidance on use of EKMA, as expressed in the Richard Rhodes memorandum (Ref. 8) which allows manipulation of input assumptions to allow calculated ozone levels to agree with observed ozone. Given the known uncertainties of this input when compared with other model inputs, it is a reasonable candidate for such adjustments.

D. Summary

In the 1982 SIP submittal, IEPA used EKMA according to procedures recommended by USEPA. In that analysis, IEPA found that the results of the EKMA analysis were not consistent with observed air quality trends. Because of these inconsistencies, IEPA recommended that those EKMA emission reduction requirements be viewed in light of these uncertainties and inconsistencies. Since the original 1982 SIP submittal, IEPA has had the opportunity to reevaluate the EKMA procedure and the data inputs that drive it. From the reassessment, it has been found that judicious selection of EKMA input data results in emission reduction requirements and model performance that are consistent with observed air quality trends and independently determined emission control requirements. Specific conclusions are presented below:

1. Determination of ozone aloft as an input to the EKMA analysis, can be done using the federal default procedure. However, in the case of northeastern Illinois, these measurements tend to overestimate ozone aloft at high upwind concentrations, and underestimate ozone aloft at low upwind concentrations. States should be encouraged to use more direct measurements to estimate ozone aloft when such measurements are available.

2. When properly operated and carefully sited, ambient NMHC and NO_x monitors are the best source of data for use in EKMA to determine initial NMHC and NO_x concentrations, and resultant NMHC/NO_x ratios. In northeastern Illinois, the location of the NMHC and NO_x monitors disqualify them from producing usable NMHC and NO_x data for modeling purposes; however, the accuracy of these monitors is acceptable to allow use of monitored data to verify, in a relative sense, inventory based NMHC/NO_x ratios that are used in the EKMA procedure. USEPA guidance that EKMA cannot be used without quality assured NMHC and NO_x monitoring data is justified, based upon the wide range of emission control requirements that result when NMHC/NO_x ratios are not accurately known. NMHC/NO_x ratios developed from inventories without supporting monitoring data may be subject to the same variations as experienced with monitor and data.

3. USEPA guidance which discourages states from using other than default chemistry assumptions as input to the EKMA model does not, in this case, diminish the ability of EKMA to be utilized to predict emission control requirements, providing that the states are able to retain judicious flexibility in evaluation of other EKMA inputs, such as mixing height and initial NMHC and NO_x concentrations, to enable the EKMA model to predict peak ozone levels that are consistent with observed ozone on the day being modeled.

4. As with any model which attempts to describe a complex physical process, inputs to that model must be sound, from a physical and rational sense, and must produce results that are consistent with observations of the real system being modeled. When used with physically realistic inputs, EKMA can produce results that are not only consistent with observed air quality, both past and present, but also produce results that are consistent with emission control requirements determined through independent means.

5. Notwithstanding EKMA's ability to predict emission control requirements that are supported by observed air quality and other modeling techniques, the emission reduction requirements produced by EKMA should be viewed as minimum requirements and reevaluated each year to ensure that the ozone NAAQS is attained and maintained in northeastern Illinois and southeastern Wisconsin.

References

1. USEPA. "Guideline for Use of City-Specific EKMA in Preparing Ozone SIPs, EPA-450/4-80-027, March, 1981 (page 5).

2. Roy F. Weston, . Final Report - Evaluation of the EKMA Model and Alternative Isopleth Models for Application in the Houston Area, November, 1981.

3. J.C. Tuijonis, et al., "Impact of Reactivity Criteria on Organic Emission Control Strategies for Los Angeles," JAPCA, October, 1978.

4. USEPA. Comparison of Ambient NMHC/NOx Ratios with NMHC/NOx Ratios Calculated from Emission Iventories, EPA-450/3-78-026, June, 1978.

5. W.C. Eaton, et al. Systems Audit of Air Monitoring Station -- 1981 Non-Methane Organic Compounds Monitoring Study, Research Triangle Institute, July, 1981.

6. D.L. Biddison, et al. Performance Audit of the Summer of 1981 Non-methane Organic Compound Monitoring Study, Research Triangle Institute, September, 1981.

7. D.L. Biddison, et al. Second Performance Audit of the Summer 1981 Non-methane Organic Compound Monitoring Study, Research Triangle Institute, October, 1981.

8. USEPA. Memorandum from Richard Rhodes to Regional Air and Hazardous Materials Division Directors, December 3, 1981.

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APPENDIX A

Table A-1

Summary of Inputs to the 1981

EKMA Calculate Mode Comparison

Location	Date	Ozone Aloft (ppm)	Mixing Height (m)	Time of Peak (LDT)	Int HC (ppm)	Int NO_x (PPM)	ADJ Ozone Aloft (ppm)	ADJ HC (ppm) to Match 1981 3.66 Ratio
Kenosha	7/23	.036	500-1050	1900	1.10	.165	.037	.604
Libertyville	7/24	.045	350-1150	1600	1.77	.173	.041	.633
Racine	8/01	.064	575-1172	1500	3.5	.49	.049	1.79
Racine	8/03	.045	510-1460	1700	1.00	.139	.041	.509
Skokie	8/04	.040	160-1000	1800	1.00	.138	.039	.505
Racine	8/05	.019	890-1300	1800	.37	.093	.030	.340
Kenosha	8/06	.037	620-930	1400	1.00	.110	.038	.403
Waukegan	8/07	.033	430-850	1500	.93	.130	.036	.476
Kenosha	8/09	.039	250-1575	1500	.47	.051	.038	.187
Waukegan	8/10	.017	220-960	1400	1.73	.208	.029	.761
Kenosha	8/11	.031	120-1820	1800	1.20	.178	.033	.651
Racine	8/12	.030	150-1890	1500	1.13	.131	.035	.479
Kenosha	8/13	.046	180-1300	1700	1.13	.136	.041	.498
Kenosha	8/14	.030	520-990	1500	1.60	.142	.035	.520
Kenosha	8/21	.087	180-1720	1800	.40	.065	.058	.238
Kenosha	8/22	.049	250-1575	1600	.20	.112	.043	.410
Kenosha	8/23	.068	250-1575	1400	.27	.074	.051	.271
Kenosha	8/24	.056	240-1760	1700	1.13	.251	.046	.919
Racine	9/11	.053	250-1300	1500	1.50	.127	.044	.465
Skokie	9/14	.051	350-800	1000	1.56	.266	.043	.973

1980 VOC Emission Density ($Kg/Hr/km^2$)		1980 NO_x Emission Density ($Kg/Hr/km^2$)
Cook Co.	14.02	9.01
Lake Co.	2.72	3.20
Kenosha Co.	2.08	2.74
Racine Co.	1.23	.83

Table A-2

1981 6 - 9 A.M. NMHC/NO_x Data
160 North LaSalle
Chicago, Illinois

Date	Total HC	Total NOx	HC/NOx Ratio
7/22	.9	.144	6.25
7/23*	3.3	.494	6.68
7/24*	5.3	.52	10.69
7/25	5.3	.445	11.91
7/28	2.9	.556	5.22
8/1*	3.5	.49	7.14
8/2	.8	.127	6.30
8/3*	2.9	.418	6.94
8/4*	3.0	.415	7.23
8/5*	1.1	.268	4.10
8/6*	3.1	.34	9.12
8/7*	2.8	.38	7.36
8/8	.6	.131	4.58
8/9*	1.4	.153	9.15
8/10*	5.2	.623	8.35
8/11*	3.6	.534	6.74
8/12*	3.4	.394	8.63
8/13*	3.4	.408	8.33
8/14*	4.8	.427	11.24
8/15	---	----	-----
8/16	---	----	-----
8/17	---	----	-----
8/18	2.9	.506	5.73
8/19	---	----	-----
8/20	1.1	.265	4.15
8/21*	.4	.065	6.15
8/22*	.6	.336	1.79
8/23*	.8	.222	3.60
8/24*	3.4	.752	4.52
8/25	2.3	.481	4.78
8/26	2.2	.386	.6.70
8/27	---	----	-----
8/28	2.4	.392	6.12

Date	Total HC	Total NOx	HC/NOx Ratio
9/01	---	----	-----
9/02	1.1	.247	4.45
9/03	3.0	.455	6.84
9/04	3.2	.565	5.66
9/05	1.1	.183	6.01
9/06	.2	.035	5.71
9/07	1.2	.171	7.02
9/08	2.4	.424	5.66
9/09	5.9	.81	7.28
9/10	2.8	.332	8.43
9/11*	4.5	.381	11.81
9/12	.9	.068	13.23
9/13	3.8	.29	13.10
9/14	4.7	.798	5.88
9/15	3.2	.344	9.30
9/16	2.9	.269	10.78
9/17	2.8	.282	9.92
9/18	4.1	.848	4.83
9/19	1.4	.123	11.38
9/20	.6	.052	11.53
9/21	2.9	.497	5.84
9/22	1.5	.221	6.79
9/23	4.1	.787	5.21
9/24	2.8	.625	4.48
9/25	3.3	.599	5.51
9/26	2.0	.176	11.36
9/27	.7	.098	7.14
9/28	3.2	.491	6.51
9/29	1.9	.419	4.53
9/30	1.3	.331	3.93

* = Ozone Conducive Day
7.17 mean (n = 57)
2.63 Std. Dev.

Table A-3

1981 6 - 9 A.M. NMHC/NO_x Air Quality Data

Huron and Fairbanks Ct.

Chicago, Illinois

Date	Total HC	Total NOx	HC/NOx Ratio	HC Adjustment Factor	New HC	New HC/NOx Ratio
7/22	.9	.133	6.76	+5%	.945	7.10
7/23*	1.2	.215	5.58	+4%	1.248	5.80
7/24*	1.9	.205	9.26	+3%	1.957	9.54
7/25	2.9	.31	9.35	+2%	2.958	9.54
7/26	1.1	.098	11.22	+1%	1.11	11.34
7/27	.8	.061	13.11	-1%	.792	12.98
7/28	1.2	.15	8.00	-2%	1.176	7.84
7/29	1.2	.312	3.85	-3%	1.164	3.73
7/30	2.1	.496	4.23	-4%	2.016	4.06
7/31	1.4	.584	2.40	-5%	1.33	2.28
8/1*	2.8	.589	4.75	-7%	2.604	4.42
8/2	.2	.087	2.30	-8%	.184	2.11
8/3*	.7	.219	3.20	-10%	.63	2.88
8/4*	--	--	--	-11%	--	--
8/5 *	.4	.175	2.29	-12%	.352	2.01
8/6*	.9	.151	5.95	-13%	.783	5.18
8/7*	2.0	.429	4.66	-15%	1.7	3.96
8/8	.1	.052	1.92	-16%	.084	1.62
8/9*	.9	.219	4.11	-18%	.738	3.37
8/10*	2.5	.568	4.40	-19%	.203	3.56
8/11*	--	--	--	--	--	--
8/11*	--	--	--	--	--	--
8/12*	--	--	--	--	--	--
8/13*	--	--	--	--	--	--
8/14*	--	--	--	--	--	--
8/15	--	--	--	--	--	--
8/16	--	--	--	--	--	--
8/17	--	--	--	--	--	--
8/18	--	--	--	--	--	--
8/19	--	--	--	--	--	--
8/20	--	--	--	--	--	--

Date	Total HC	Total NOx	HC/NOx Ratio	HC Adjustment Factor	New HC	New HC/NOx Ratio
8/21*	1.6	.153	10.46	-31%	1.104	7.22
8/22*	1.0	.248	4.03	-31%	.69	2.78
8/23*	.9	.194	4.64	-31%	.621	3.20
8/24	3.7	.709	5.22	-31%	2.55	3.60
8/25	1.6	.24	6.67	-31%	1.104	4.60
8/26	1.6	.235	6.80	-31%	1.104	4.70
8/27	--	--	--	-31%	--	--
8/28	1.0	.357	2.80	-31%	.69	1.93
8/29	1.0	.113	8.85	-31%	.69	6.11
8/30	2.8	.223	12.55	-31%	1.932	8.66
8/31	--	--	--	-31%	--	--
9/1	--	--	--	-31%	--	--
9/2	.6	.097	6.19	-31%	.414	4.26
9/3	.9	.259	3.47	-31%	.621	2.40
9/4	.8	.264	3.03	-31%	.552	2.09
9/5	.6	.107	5.61	-31%	.414	3.87
9/6	--	--	--	-31%	--	--
9/7	.4	.061	6.56	-31%	.276	4.52
9/8	--	--	--	-31%	--	--
9/9	--	--	--	-31%	--	--
9/10	--	--	--	-31%	--	--
9/11*	.7	.307	2.28	-31%	.483	1.57
9/12	1.1	.09	12.22	-31%	.759	8.43
9/13	1.3	.115	11.30	-31%	.897	7.80
9/14*	1.7	.241	7.05	-31%	1.173	4.87
9/15	1.2	.128	9.38	-31%	.828	6.47
9/16	1.5	.299	5.02	-31%	1.035	3.46
9/17	1.5	.235	6.38	-31%	1.035	4.40
9/18	.6	.094	6.38	-31%	.414	4.40
9/19	1.6	.13	12.31	-31%	1.104	8.49
9/20	.5	.044	11.36	-31%	.345	7.84
9/21	1.5	.252	5.95	-31%	1.035	4.11
9/22	.9	.07	12.85	-31%	.621	8.87
9/23	2.0	.502	3.98	-31%	1.38	2.75
9/24	1.8	.375	4.80	-31%	1.242	3.31
9/25	.8	.356	2.25	-31%	.552	1.55
9/26	.6	.158	3.80	-31%	.414	2.62
9/27	.2	.052	3.85	-31%	.138	2.65
9/28	.7	.323	2.17	-31%	.483	1.50
9/29	.7	.196	3.57	-31%	.483	2.46
9/30	.3	.174	1.72	-31%	.207	1.19
n=5	6.09 mean (n = 53)				4.75 mean (n = 53)	
	3.30 std dev.				2.77 std. dev.	

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June 1977

Sears Tower

	3.00 m	6.00 m	9.00 m	Wind	KKK (1200)	KKK (1100)	KKK (1100)				Conditions	Mixing Height	
1	049	017	045	25	—	—							1
2	016	021	028	33	—	—							2
3	020	022	043	28	—	—							3
4	064	045	056	24	—	—							4
5	036	034	061	07	—	—							5
6	072	027	044	18 K	—	—							6
7	065	016	039	18 K	035	042	038						7
8	026	012	033	02	011	006	010						8
9	040	024	042	32	055	—	—						9
10	—		—	20 K	—	—	—						10
11	—		—	19 K	—	—	—						11
12	—		—	33	039	035	037						12
13	—		—	03	029	042	035						13
14	—	—	—	10	030	035	033						14
15	040	017	048	17 K	—	—							15
16	046	033	022	17 K	016	042	024						16
17	047	059	079	19 K	067	073	070						17
18	022	030	036	27	037	042	034						18
19	057	029	057	18 K	—	—	—						19
20	066	043	095	20 K	056	056	056						20
21	020	029	035	31	—	029	—						21
22	018	029	—	14	034	050	045						22
23	—	—	—	11	019	026	022						23
24	—	—	—	13	072	077	075						24
25	—	—	—	18 K	015	012	013						25
26	—	—	—	20 K	040	044	042						26
27	—	—	—	22 K	052	057	055						27
28	—	—	—	36	077	080	076						28
29	—	—	—	07	064	062	063						29
30	072	070	046	30	040	041	041						30
31													31
	40.9	28.5	47.6										

July 1978

Sears Tower

	9 AM	6 PM	4 PM		KKK 10 AM	KKK 11 AM	KKK Ave				Conditions	Mixing Height	
1	052	054	049	10	046	063	054						1
2	026	041	050	10	041	047	044						2
3	041	042	048	09	034	058	046						3
4	072	068	071	09	071	117	094				[illegible]		4
5	080	076	077	16 K	052	055	053				[illegible]	[illegible]	5
6	056	042	066	19 K	064	078	074				[illegible]	[illegible]	6
7	072	057	059	21 K	045	062	053						7
8	055	053	046	03	045	062	054						8
9	049	049	054	09	048	058	053				[illegible]		9
10	036	030	037	03	029	024	026						10
11	058	036	046	08	020	019	019						11
12	045	054	051	16 K	036	048	042						12
13	037	023	029	22 K	016	021	018						13
14	041	022	039	24	055	054	054				[illegible]	[illegible]	14
15	056	057	039	09	054	061	060				[illegible]		15
16	097	092	092	06	020	034	027				[illegible]		16
17	093	036	024	16 K	026	044	035				[illegible]	[illegible]	17
18	029	047	058	20 K	056	064	060						18
19	077	043	—	18 K	058	063	060						19
20	068	044	085	09	055	068	062				[illegible]	—	20
21	099	036	060	07	065	065	065				[illegible]	[illegible]	21
22	052	040	089	20 K	060	061	061				[illegible]		22
23	021	030	037	01	012	011	011						23
24	049	041	054	07	028	031	029						24
25	045	032	058	20 K	041	048	045				[illegible]		25
26	050	038	061	22 K	—	—							26
27	—	—	—	36	039	041	040				[illegible]	[illegible]	27
28	041	040	046	17 K	022	022	022				[illegible]	[illegible]	28
29	057	045	039	29	042	027	034						29
30	029	034	041	05	011	021	016						30
31	044	026	033	23	039	042	040				[illegible]	[illegible]	31
	45.6	40.7	50.6										

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August 1978

Sears Tower

	3:00	6:00	9:00	[illegible]	kkk 10:00	kkk 11:00	kkk Ave				Conditions	Mixing Height	
1	033	035	036	09	034	046	040				[illegible]	[illegible]	1
2	048	014	032	20	011	009	010						2
3	039	037	043	02	031	040	034						3
4	044	031	037	07	035	042	039						4
5	061	049	054	22	054	067	063						5
6	052	056	059	09	047	055	051				[illegible]	—	6
7	029	018	027	07	030	034	032				[illegible]	[illegible]	7
8	053	031	049	20	054	056	057						8
9	052	022	038	25	060	072	066						9
10	052	039	048	07	028	034	031						10
11	026	052	039	14	003	003	003						11
12	056	037	061	16	040	045	042				[illegible]	—	12
13	044	043	055	16	052	056	053				[illegible]		13
14	075	057	074	17	064	066	065				[illegible]	[illegible]	14
15	041	052	064	17	048	047	047						15
16	022	020	035	23	028	028	028						16
17	038	037	018	18	004	010	007				[illegible]	[illegible]	17
18	047	033	020	17	032	046	034						18
19	029	022	030	27	039	040	039						19
20	048	034	051	07	052	062	057				[illegible]		20
21	046	042	047	19	048	046	047				[illegible]	[illegible]	21
22	080	048	046	19	065	053	059				[illegible]	[illegible]	22
23	080	072	080	19	069	071	070				[illegible]	[illegible]	23
24	080	045	027	21	018	017	018				[illegible]	[illegible]	24
25	070	048	032	01	022	028	025				[illegible]	[illegible]	25
26	026	061	044	07	020	036	028						26
27	073	068	052	19	037	048	043						27
28	021	020	033	26	023	026	024						28
29	021	020	032	31	022	025	023						29
30	043	041	047	05	024	030	027				[illegible]	[illegible]	30
31	047	026	036	06	027	043	035						31
	50.1	42.4	45.3								[illegible]	[illegible]	

June 1979

Sears Tower

	3am	6am	9am	Wind Dir 9am	← KK 10am	KK 11am	Aug →	← 10am	Elgin 11am	Aug →	Sunrise	Mixing Height	
1	014	005	022	35- E32	009	022	015	032	038	035			1
2	030	035	045	22K K22	026	034	030	048	051	050	425	—	2
3	038	041	047	25E E26	032	049	050	051	054	053	425	—	3
4	037	032	033	25E E26	044	046	045	059	059	054			4
5	036	040	062	02- -03	041	054	048	040	049	045			5
6	034	030	037	07- -10	053	055	054	065	073	069	426	[illegible]	6
7	025	016	010	18K -10	007	001	004	020	017	018			7
8	016	017	028	18K -06	031	037	034	053	050	031	425	[illegible]	8
9	012	011	020	07- -07	032	043	038	037	060	043			9
10	017	010	017	25E E25	011	019	012	025	026	026			10
11	035	017	030	29E E30	021	026	024	038	043	040			11
12	011	027	054	06- -06	029	031	027	—	—	—			12
13	016	035	034	13- K14	021	025	023	—	—	—			13
14	036	012	029	19K K19	051	055	053	—	—	—			14
15	047	038	066	20K K21	053	059	056	084	089	084			15
16	—	—	—	19K K19	—	—	—	072	075	073			16
17	023	027	038	05- E27	032	037	035	031	035	033			17
18		—	—	04- -07	—	—	—	022	019	018			18
19	032	043	030	12- -11	032	042	037	044	059	052			19
20	032	—	023	17K K18	—	—	—	051	056	053			20
21	028	028	040	26E E23	026	033	030	044	045	045			21
22	025	029	031	02- E31	038	042	040	047	050	048			22
23	029	031	034	03- -01	043	044	044	034	034	037			23
24	028	034	033	04- -05	030	031	030	046	049	047			24
25	023	026	061	07- K13	033	040	036	[illegible]	062	061			25
26	045	036	048	20K -11	042	050	046	—	—	—	425	[illegible]	26
27	031	025	029	22K E23	031	037	034	—	—	—			27
28	038	030	045	07- -11	040	050	045		—	—	425	[illegible]	28
29	019	011	024	27E -11	015	020	017		—	—			29
30	049	042	045	34- E36	038	038	038		—	—	425	—	30
31									—	—			31
	29.0	28.4	37.0										

July, 1979

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Struts Tower

	Storm	Gust	Gust	Wind	← K 10'	K K 11'	Ave →	← E 10'	Gust 11'	Ave →	Conduit	Mixing Height	
1	025	024	034	35 - 31 E	027	028	028	—	—	—	Yes		1
2	028	021	026	04 - 02 -	030	031	030	—	—	—			2
3	032	040	028	17K 16K	025	023	024	046	042	044	Yes	[illegible]	3
4	036	027	033	02 - 04 -	017	028	022	040	039	039			4
5	030	032	035	04 - 02 -	020	022	021	033	036	034			5
6	036	040	038	06 - 06 -	032	034	033	038	038	038			6
7	043	040	054	09 - 16K	040	047	043	054	072	063	Yes	—	7
8	053	618	[illegible]	08 - 14K	028	022	025	090	102	096			8
9	048	042	047	07 - 08 -	028	036	032	063	073	068	Yes	[illegible]	9
10	034	049	057	21K 22K	075	080	078	069	067	068	Yes	[illegible]	10
11	034	040	037	20K 21K	043	043	043	077	083	080		[illegible]	11
12	053	025	055	09 - 00 E	036	042	039	071	084	078	Yes	[illegible]	12
13	074	052	024	19K 18K	041	052	046	058	062	060	Yes	[illegible]	13
14	027	027	031	29 E 25 E	022	017	020	040	039	040			14
15	029	041	039	25 E 27 E	030	033	031	043	046	045	Yes	[illegible]	15
16	030	024	025	35 - 01 -	039	040	040	020	025	022			16
17	022	019	022	01 - 03 -	011	011	011	—	030	—			17
18	033	030	033	03 - 35 E	—	—	—	045	049	047			18
19	035	023	036	06 - 26 E	—	—	—	053	055	054	Yes	[illegible]	19
20	036	039	039	06 - 28 E	064	069	064	070	074	072	Yes	[illegible]	20
21	040	060	067	29 E 24 E	093	093	093	080	082	081	Yes	[illegible]	21
22	058	030	039	19K 07 -	071	067	069	059	073	066			22
23	043	020	049	19K 20K	050	054	052	088	086	087			23
24	005	007	013	18K 18K	000	004	002	034	039	037			24
25	012	009	024	29 E 23 E	004	011	008	046	041	043			25
26	030	021	020	07 - 07 -	012	027	019	030	038	034			26
27	055	025	035	21K 17K	021	028	025	049	058	054	Yes	[illegible]	27
28	008	005	035	36 - 29 E	013	016	014	034	042	038	Yes	—	28
29	039	044	037	05 - 01 -	029	037	033	047	056	051	Yes		29
30	033	008	045	19K 06 -	004	015	009	027	035	031			30
31	028	017	044	36 - 30 E	015	—	[illegible]	047	050	048			31
	35.9	29.2	37.5										

August 1979

Sears Tower

	3:00	6:00	9:00	Wind	← KKK 10:00	11:00	Ave →	← Elgin 10:00	11:00	Ave →	Conducive	Mixing Height	
1	033	020	016	01- 02-	—	—	—	022	021	022			1
2	013	013	033	25K 28E	029	029	029	041	048	044	Yes	200-1200	2
3	041	043	024	22K 20K	025	027	026	055	056	056	Yes	280-1200	3
4	048	021	039	19K 20K	029	031	030	054	046	050	Yes	—	4
5	029	028	033	17K 34E	032	038	035	028	027	027			5
6	055	038	030	05- 03-	024	032	028	037	046	041	Yes	360-1550	6
7	020	021	051	23E 24E	032	039	036	060	063	062			7
8	017	—	—	03- 02-	048	055	052	047	065	056	Yes	290-1250	8
9	013	042	032	18K 17K	017	030	023	043	068	054	Yes	355-1400	9
10	039	029	018	32- 28E	010	010	010	—	—	—			10
11	029	025	031	03- 03-	014	016	015	—	—	—			11
12	023	019	051	23E 20E	029	030	030	—	—	—			12
13	031	019	017	22K 23E	020	027	023	—	—	—			13
14	019	010	014	30E 31E	007	012	010	—	—	—			14
15	026	025	024	03- 04-	—	—	—	—	—	—			15
16	022	028	021	18K 15K	—	—	—	—	—	—			16
17	042	024	023	18K 19K	019	027	023	—	—	—			17
18	016	018	022	22K 24E	011	014	013	—	—	—			18
19	046	048	040	07- 00E	023	028	025	—	—	—			19
20	021	030	036	08- 11-	005	009	007	—	—	—			20
21	023	040	047	08- 09-	011	013	011	025	044	035			21
22	013	016	016	16K 16K	012	020	016	036	044	040			22
23	028	018	025	20K 18K	021	024	023	037	039	038			23
24	010	012	019	26E 27E	011	019	012	026	029	027			24
25	022	018	028	12- 29E	016	029	022	032	039	036			25
26	019	018	036	10K 17K	027	028	028	049	062	056			26
27	023	019	015	19K 18K	015	023	019	042	043	042			27
28	035	029	035	09- 08-	010	020	015	047	062	055			28
29	025	046	013	22K 28E	019	021	020	039	044	041	Yes	550-1350	29
30	030	020	031	22K 26E	017	032	024	043	050	047	Yes	140-1480	30
31	034	036	036	17K 17K	039	039	039	060	068	064			31
	31.4	23.4	28.5										